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ABSTRACT

This book is written for use only in the Air Force ROTC program and cannot be purchased on the open market. The book describes the historical development of aerospace industry. The first chapter contains a brief review of the aerospace environment and the nature of technological changes brought by the aerospace revolution. The following chapter discusses how ancient men learned about basic aerodynamic principles. The third chapter contains a description of how the first airplane was developed and subsequent modifications in design, speed and comfort. Finally, the evolution of spacecraft is described, as well as possible future developments in the aerospace industry. (Author/PS)

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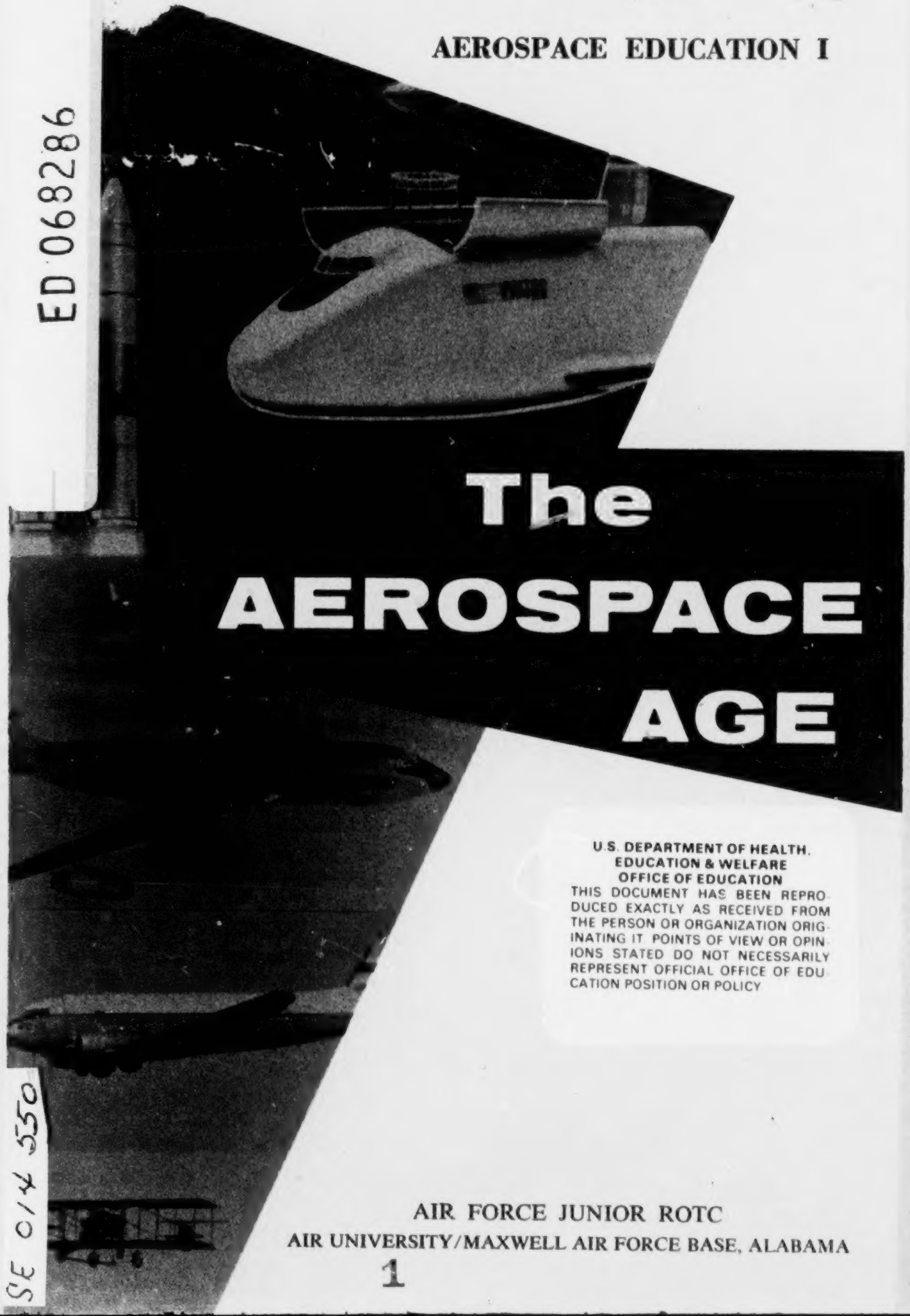

The AEROSPACE AGE

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Aerospace Education I

The Aerospace Age

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Academic Publications Division
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AIR FORCE JUNIOR ROTC
AIR UNIVERSITY
MAXWELL AIR FORCE BASE, ALABAMA

1971

This publication has been reviewed and approved by competent personnel of the preparing command in accordance with current directives on doctrine, policy, essentiality, propriety, and quality.

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Preface

THE RAPID GROWTH of science and technology in the twentieth century is nowhere more obvious than in the fulfillment of man's ancient dream of flying through the air. Born within the lifetime of most people living today, the airplane and, more recently, space vehicles, have removed the barriers of time and space from man's ability to move from one place to the other. The modern airplane represents one of the earliest technologies to require a close association of scientists, engineers, and industrialists. No single human mind could acquire the knowledge or develop the skills necessary to design, build, and operate a jet aircraft or a space vehicle like the Apollo. Modern man has become accustomed to numerous technological developments, such as nuclear energy, high-speed electronic computers, and automated machinery. But it was the airplane that first advanced from the creation of a pioneer inventor to the work of specialists who coordinate their efforts for a product far beyond the capacity of a single individual.

The purpose of this unit is to describe the evolution of mechanical flight from the time that man could only dream of flying to the modern Aerospace Age when human flight has become almost as routine as travel by automobile. The first chapter contains a brief view of the aerospace environment and the nature of technological changes brought by the aerospace revolution. The chapter describes how man, in a relatively short period, advanced the flying machine from the simple design of the Wright brothers' biplane to the complexities of the Apollo spacecraft.

In the second chapter, the story shifts to ancient man and his early efforts to imitate the flight of birds. For centuries, he considered the problem of human flight only in terms of simple downward and backward arm motions similar to swimming in water. Not until he learned to adapt his machines to the flow of air about them did he achieve sustained and controlled flight. Although his experiences with balloons and dirigibles led him for a brief period away from his primary objective of winged flight, they enabled him to learn more about basic aerodynamic principles that control the flight of winged aircraft.

Sir George Cayley was the first man to set forth the basic aerodynamic principles that led to the development of the airplane. Beginning with Cayley's experiments, the text traces the process by which man learned to propel a winged aircraft through the air. The story is one of constant change as the airplane advanced through a series of complicated steps that ultimately brought modern aerospace flight. Not only did the shape and design of the airplane change as its speed increased from 30 to 4,000 miles per hour. Aviation technology also advanced from piston to jet engines, from wood and fabric construction to steel, aluminum, and titanium, and from bridgelike trusses to thin metal shells reinforced by metal beams. Then came the rocket and the fantastic flights of spacecraft to the moon and outer space. Finally, the text provides the reader with a glimpse into the future and further momentous developments as aerospace technology continues to advance.

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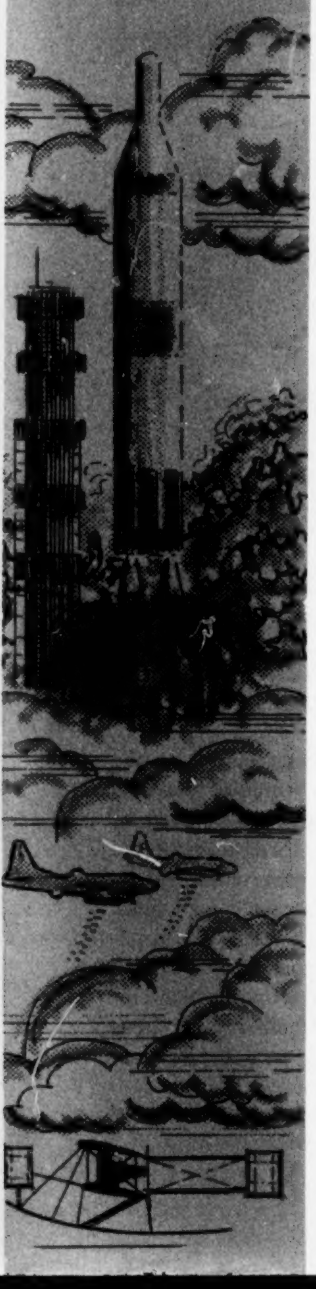

Chapter 1

An Introduction

THIS CHAPTER is an introduction to the Aerospace Age and its impact on modern transportation systems. First, it describes the achievements of winged aircraft in setting new records for speed, distance, and altitude and the effects of rapid technological change on world travel. Next, it provides a brief review of man's accomplishments in the space environment, with primary attention to the scope and impact of the Apollo program. When you have studied this chapter, you should be able to do the following: (1) discuss the impact of the Aerospace Age on man's ability to transport himself from place to place; (2) identify some of the major aerospace developments since the introduction of the Air Age in 1903 and the Space Age in the late fifties; and (3) describe the scope of the US manned space program.

HUMAN PROGRESS is closely linked to the development and improvement of transportation systems. Even before the invention of the wheel, man used sleds and similar conveyances to move from place to place. As crude as early modes of transportation were, they played a major role in the lives of individuals and groups of individuals. They provided the necessary mobility for the satisfaction of physical needs, but, more importantly, they encouraged the exchange of ideas and the development of human associations. They were, in effect, controlling forces in the evolution of civilized society.

The discovery of the wheel marks the first major advance in man's quest for better transportation (Fig. 1). With the wheel, man entered a world of machinery and mechanical change. Through the centuries, he

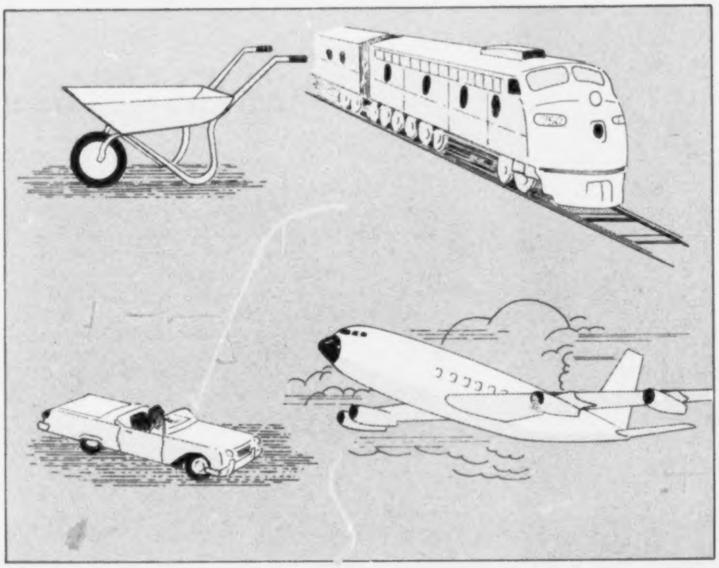

Figure 1. Discovery of the wheel led to modern transportation systems.

developed the wheelbarrow, two- and four-wheeled carriages, the steam locomotive, the automobile, the ocean liner, and the airplane—all designed to carry cargoes faster and farther. Each new development was a step forward in the search for better transportation; each brought a revolution in the lives of people.

No other mode of transportation has had a greater impact on the world than aviation. When man discovered the secret of powered flight, he shrank the world and provided the means eventually of reaching any point on the earth's surface in a day's travel time. Before the airplane, he was confined to land and water transportation and restricted by natural barriers, such as mountains, oceans, and forests. Aerospace contains no such physical barriers. It is a vast area extending upward and outward from the earth's surface, consisting of atmosphere, a transition zone, and space. It is a field of activity which embraces both **aeronautics*** and **astronautics.**** It extends into all areas of human endeavor, including national security, space exploration, transportation, and communication. The aerospace environment provides an almost unlimited medium for man to reach remote spots on the earth, world population centers—and even the moon.

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* The art, science, or business of designing, manufacturing, and operating vehicles that move through the air.

** The art or science of designing, building, and operating space vehicles.

THE AEROSPACE ENVIRONMENT

In Cleopatra's day, Anthony could travel no faster than his horse could carry him. Eighteen centuries later, Benjamin Franklin, a versatile inventor in a young and rapidly developing nation, still could travel no faster than his most able horse. Then, at Rainhill, England, in the 1830s, George Stephenson's steam locomotive proved that man could move on the earth's surface at the startling rate of almost 50 miles per hour. In the early days of the Air Age 100 years later, a pilot named Jimmy Doolittle shattered all records when he flew an airplane at a speed of 252 miles per hour. Then came World War II, and the quest for speed in 1944 led to the production of fighter planes clocking 470 miles per hour.

For something like 50,000 years, man had been accustomed to traveling no faster than 35 miles per hour. Suddenly, in a period of approximately 100 years, he became able to travel from 50 to 470 miles per hour as a matter of routine. During an additional few years following World War II, he broke heat and sound barriers within the earth's atmosphere at speeds over 2,000 miles per hour. Aerospace research vehicles have achieved speeds greater than 4,000 miles per hour at altitudes over 350,000 feet. The Boeing 747 jumbo jet carries as many as 490 passengers at **subsonic*** speeds well over 600 miles per hour, and the time is at hand when **supersonic**** airliners like the French Concorde and the Russian Tupolev TU–144 will transport people at speeds of 1,200 to 1,550 miles per hour. The capstone of all speed records came with the Apollo flights when man achieved speeds up to 25,000 miles per hour through space.

Unbelievable rates of speed with which modern man moves from place to place are fantastic achievements in themselves. Perhaps the most startling thing about the Aerospace Age is the bursting technology and rapid change which it represents. The Stone Age lasted almost 50,000 years. In the twentieth century alone, man has moved in swift succession through the Air Age, the Atomic Age, the Missile Age, the Space Age, to the Aerospace Age, intermixed with electronics and automation. Technology rushes headlong into the future; the newest suc-

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* Pertaining to speeds less than the speed of sound.

** Pertaining to the speed of an object moving at a speed greater than mach.

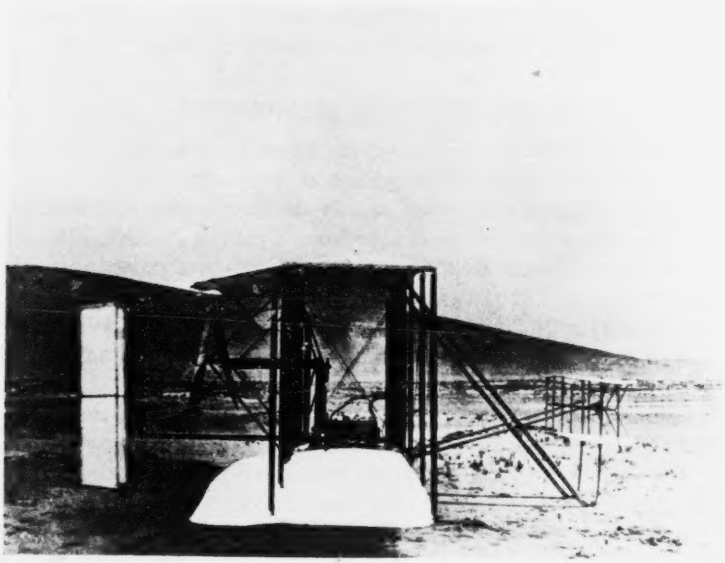

Figure 2. Wright *Flyer No. 3* introduced the Air Age.

ceeds the new. Man advances so rapidly from one age to another that a relatively short period of time can bring an entirely new age with new changes and innovations.

The Air Age

The Wright brothers introduced the Air Age in 1903 with a glider equipped with a rebuilt automobile engine (Fig. 2). Their first *Flyer* remained in the air for 12 seconds at a speed of 30 miles per hour. Their third *Flyer* reached a speed of 38 miles per hour and, in their words, "conquered the air." Following the **Wright brothers'** achievements, improvements in aircraft design came in rapid succession as aviation enthuiasts in America and Europe demonstrated the miracle of flying to thousands of people.

Comparisons of modern aircraft with those of earlier years are almost as impossible as comparisons of modern automobiles with covered wagons. For example, it took **Charles A. Lindbergh** 33½ hours in the *Spirit of St. Louis* to cross the Atlantic Ocean. Military and commercial jets of today fly the same route taken by Lindbergh in less than one-third the time. People now travel coast to coast in the United States by jet aircraft in less than four hours, approximately one-half the time required by aircraft with piston engines and 16 times faster than the best rail service. They can travel to the capital of any country in the world more readily than George Washington could reach Philadelphia by stagecoach from Mount Vernon. In 1903, a man in New York planning to spend Christmas day in California would have allowed at least four days for travel by train. If he had an automobile, he would have left New York by the middle of October to reach California in time for Christmas. Today, he can telephone his travel plans to California early on Christmas morning and arrive by jet flight in time for dinner.

Some of the most amazing advances in aerospace have come during the past 10 or 15 years. Not only has man continued to set speed and altitude records; he has added rockets, missiles, and **aerospace vehicles*** to his inventory. At the same time, he has improved the endurance and usefulness of **winged aircraft.** In 1958, an Air Force C–133 Cargomaster established a weight lifting record when it carried 117,000 pounds of cargo to an altitude of 10,000 feet. Ten years later, the C–5 Galaxy, the giant of aircargo transportation, became operational with jet engines twice as powerful as any in existence (Fig. 3). This plane has a cargo floor longer than the first flight made by the Wright brothers. Its cargo compartment will house six Greyhound buses or 100 Volkswagens. It can span the Pacific Ocean non-stop from California to Japan in a matter of hours and carry a cargo of 265,000 pounds under emergency conditions a distance of 2,700 nautical miles. Also during this period came the initial flights of supersonic bombers and airliners, **mach** 3-plus fighters (more than three times the speed of sound), and mach 8 research aircraft. The Air Force F–111A, for example, is supersonic and is the world's first aircraft to use **variable sweep wings.** This feature enables the pilot to extend the wings for quick takeoff and sweep them back for high speeds. This plane has a top speed of mach 2.5 (approximately 1,900 miles per hour) at 60,000 feet and a **transoceanic** range without refueling.

Similar advances occurred in commercial and civilian aviation during the same period. The Soviet Union launched the first supersonic transport, the Tupolev TU–144, capable of carrying 120 passengers at 1,550 miles per hour. Almost 4,000 commercial jet transports from

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* A reference to three kinds of flying vehicles—the aircraft that flies within the atmosphere, the space-air vehicle that flies both within and above the sensible atmosphere, and the true spacecraft that flies principally in space either in orbit or under directional control.

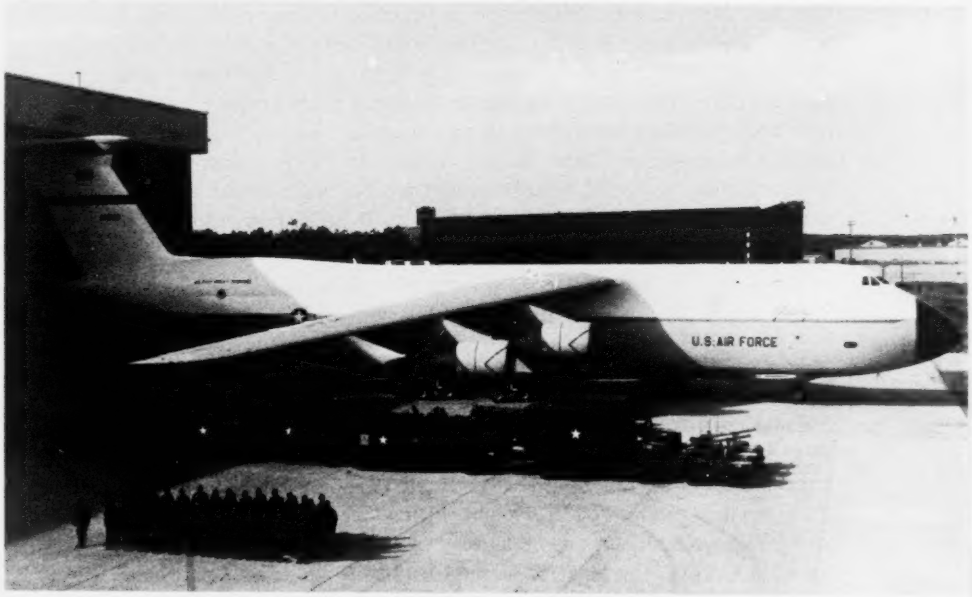

Figure 3. C–5 Galaxy—the world's largest airplane.

countries in all parts of the world flew on regular schedules. Great numbers of **maltiengine** (more than 1 engine) turbojet executive-type aircraft flew from airports in small urban communities, connecting them with the airports of major cities. So massive had air travel become that the public viewed with increasing alarm problems of air pollution and traffic congestion, the byproducts of powerful engines and human demands for speed.

In 1954, the Boeing 707 jet revolutionized air-passenger transportation with far greater speed, comfort, and safety than had been possible with propeller-driven aircraft. Fourteen years later, in 1968, this huge transport, with its capacity for 180 passengers, appeared to shrink when the Boeing 747 jumbo jet rolled from the assembly lines. The 747 is the world's largest and fastest commercial airliner designed to fly below the speed of sound (Fig. 4). Other recent additions to the family of "advanced technology jets" include the McDonnell-Douglas DC–10 and the Lockheed L–1011 **airbuses** designed to fly over ranges from 300 to 3,200 miles at speeds up to 600 miles per hour.

These are only examples to show the extent to which aviation has

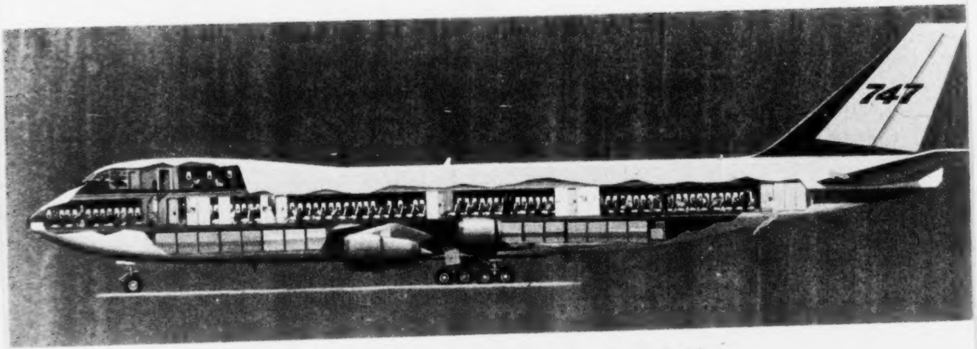

Figure 4. Boeing 747—the world's largest commercial airliner.

progressed over the short period of 60 or so years. Numerous other modern aircraft, ranging from small one-man helicopters, two-passenger private planes, racing planes, and 25-passenger airliners to supersonic military and commercial aircraft, have equally distinguishing features adapted to unique needs and requirements. As technology continues to advance, still another miracle of the Air Age appears—the supersonic airliner capable of carrying people from the United States to Europe in less than three hours. Already being tested are aircraft with vertical takeoff and landing capabilities provided by jet engines instead of spinning rotor blades. Such aircraft will revolutionize commuter and interurban travel.

This is the Air Age—a time when one instrument of flight barely becomes familiar before another appears. What is current today is obsolete tomorrow. From a two-dimensional world of surface and subsurface travel, man has created a three-dimensional world through a vast ocean of air which makes oceans on the earth seem like ponds in comparison. He now measures distance not in miles, but in terms of minutes, hours, light-years, and parsecs (3.26 light-years). He has learned that the earth is not round and that the most direct route to the Orient requires heading north, not west. He streaks through the air faster than the speed of sound and strives impatiently for new systems. In the process, he creates strange new problems that either threaten him and his environment or pose challenges for further accomplishments.

The Space Age

The decade of the 60s saw miraculous advances in the technology of winged flight. The most spectacular and electrifying achievements, however, came with the launching of the Space Age. For centuries, man had dreamed of traveling through space to the moon and planets. He had experimented with rockets, designed spaceships, and nibbled at the edge of space in balloons and winged aircraft. And then suddenly, in July 1969, after a breathtaking flight across 233,000 miles of space at speeds up to 25,000 miles per hour, he left his footprints on the face of the moon while more than 500 million of his fellows watched on their television sets. This was the pinnacle of technological achievement—the age of electronics, missiles, rockets, and automation, each playing an appropriate role as three American astronauts completed their lunar visit and returned to the planet Earth.

Man's trip to the moon actually began on 4 October 1957 when the Soviet Union launched **Sputnik I,** the world's first man-made moon. This spherical satellite weighed 184 pounds and carried two battery-powered radio transmitters. Quickly on the heels of Sputnik I came Sputnik II on 3 November 1957, weighing 1,120 pounds and carrying a live dog, medical recording equipment, radio transmitters, and instruments for recording X-rays and cosmic rays. On 31 January 1958, the United States launched its first orbiting satellite, **Explorer I,** weighing 18 pounds with a payload of instruments for checking cosmic rays, temperature, and **micrometeoroids.*** Since 1958, with names unheard of only a few years ago, such American satellites as Explorer, Vanguard, Echo, Ranger, Telstar, Relay, Syncom, Mariner, Nimbus, Tiros, Comsat, and others have orbited the earth, moon, sun, and several planets. In slightly over 10 years, the United States alone has launched more than 240 space flights involving as many as 90,000 scientists, 20,000 industrial firms, and 100 universities.

Manned spaceflight represents the most dramatic achievement of the Aerospace Age primarily because man proved that he could live and function in the hostile space environment. By nature, man can only adapt to an environment closely resembling the earth's environment. His survival depends upon adequate oxygen, atmospheric pressure, temperature control, and the absence of toxic agents. To maintain such an environment in space, he must carry hundreds of pounds of complex equipment with him and learn to cope with problems associated with confinement, isolation, and radiation. To reach the space environment, he must overcome high-gravity forces within the earth's atmosphere, control his spacecraft, and then return to the earth. The technology of manned spaceflight requires the knowledge gained from unmanned satellites and the mechanical design for human survival and flight control. With the Apollo flights to the moon, man demonstrated that he could master unbelievably complex problems of design, fabrication, assembly, propulsion, control, and communication necessary for human flight in space. In little more than a decade, he advanced from the technology of a tiny Explorer I satellite the size of a grapefruit to the technology of Apollo, a mechanical monster 36 stories high weighing millions of pounds.

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* A very small, solid body encountered by earth satellites, probes, or the like.

The manned space program in the United States began with the organization of **Project Mercury** in October 1958. Shortly thereafter, in 1961, people gazed in disbelief as they observed what appeared to be the enactment of science fiction drama. First came the announcement that Russian Cosmonaut **Yuri Alekseyevitch Gagarin** was orbiting the earth aboard a five-ton spacecraft at altitudes of 110 to 188 miles and speeds greater than 17,000 miles per hour. Soon after this event, a similar Russian spacecraft traveled more than 400,000 miles around the earth at a speed of about 17,000 miles per hour. In the same year, American Astronaut **Alan B. Shepard** made a suborbital* flight at a top speed of 5,000 miles per hour and landed 15 minutes later about 300 miles from Cape Kennedy, Florida (Fig. 5). Less than a year later, Astronaut **John H. Glenn, Jr.,** made the first American orbital flight at a speed of almost 17,500 miles per hour. During a period of three years, six different flights under Project Mercury proved that high-gravity forces at launch and weightlessness in orbit does not affect man's ability to operate in space.

Following the Mercury flights came even more astounding feats in space as pairs of American astronauts made 10 different spaceflights under **Project Gemini** between March 1965 and November 1966. Just as Project Mercury proved that manned spaceflight was possible, Project Gemini marked the beginning of two-man flights in larger spacecraft for periods as long as 14 days (Fig. 6). The Gemini flights included numerous scientific and technical experiments ranging from simple visual definitions to complex orbital docking and rendezvous procedures. These experiments provided further proof that man could perform efficiently under the rigid requirements of the space environment.

The Apollo project is the largest and most complex technological program ever undertaken by man. The giant Saturn 5 rocket and the 3.5 million parts in the Apollo spacecraft symbolize the highest point

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* The flight of a satellite on an orbiting trajectory, but ending short of a complete orbit.

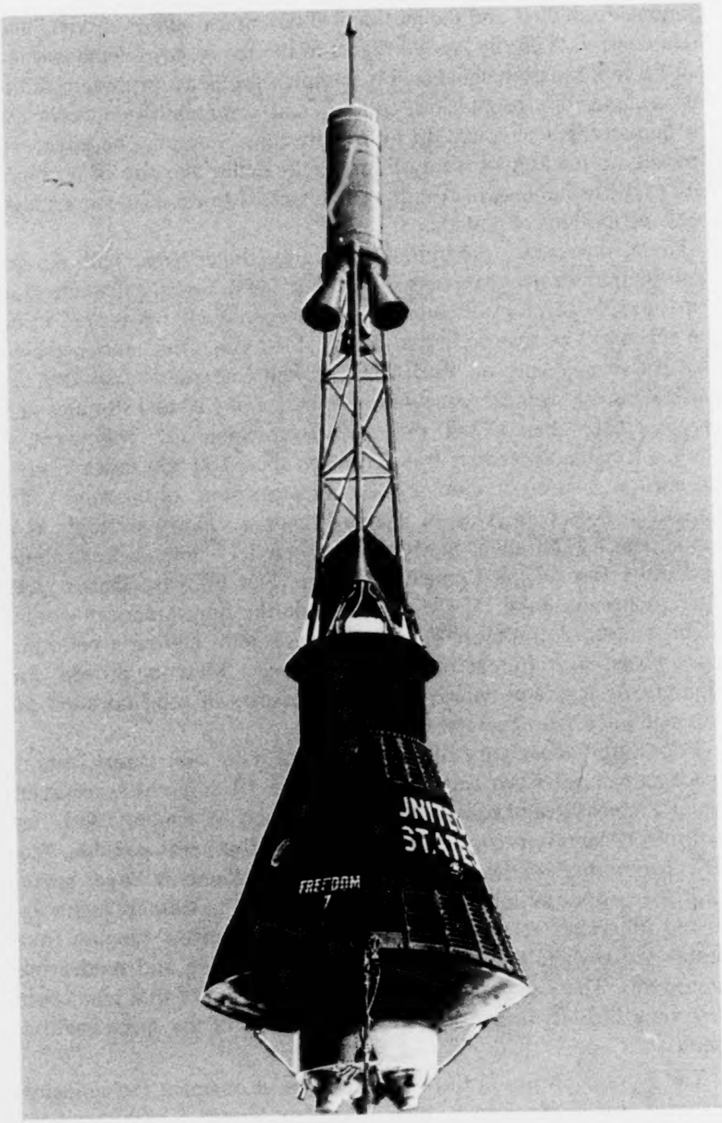
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Figure 5. The US manned space program began with Project Mercury, which used small one-man capsules to prove man's ability to operate in space.

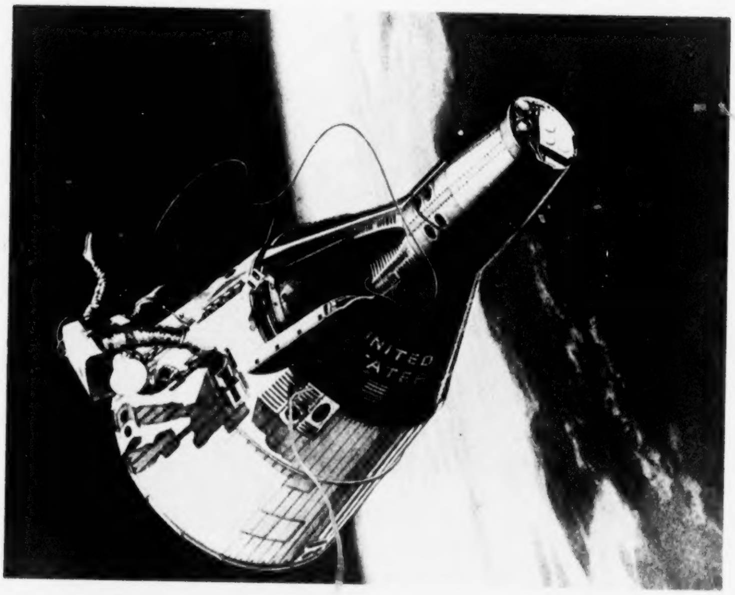


Figure 6. Project Gemini was a follow-on program to Project Mercury, which included orbital flights of longer duration and complex maneuvering procedures, such as docking and rendezvous.

in engineering and manufacturing achievements of the twentieth century. Not only did the task of building the **Saturn 5/Apollo** spacecraft require entirely new approaches to engineering problems, the facilities for transporting and assembling the various stages of the Apollo system are themselves miracles of engineering technology. Both the Apollo and its ground support facilities are first-hand examples of man's technological progress since the days of the Wright brothers (Fig. 7).

The Apollo was designed under extreme weight limitations to operate in an airless, weightless environment. This required the development of lightweight materials and miniature electronic components that engineers had never considered before. To save weight, engineers developed new types of paint and insulation. They built delicate computers and navigation equipment with many components too small for the naked eye to see. The 12-foot tall Apollo command capsule contains enough electrical wiring for 50 two-bedroom homes, and in the Saturn 5 rocket are 2.5 million soldered electrical connections. So deli-

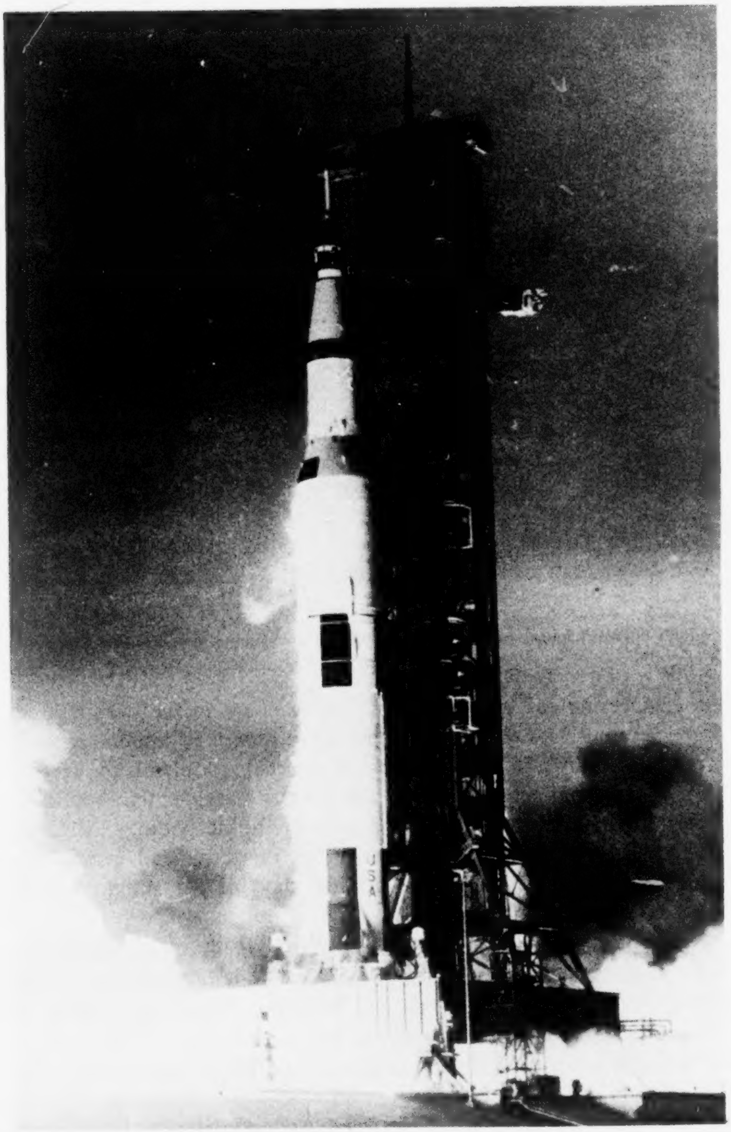


Figure 7. The Saturn V/Apollo was the world's first space vehicle to carry men to the moon and return them safely to earth.

cate is the floor of the lunar landing vehicle that workmen stand on a device similar to a diving board while they work.

The Saturn 5 launching system consists of three different rockets stacked vertically. At various stages of launch, these rockets develop a total power equivalent of approximately 160 million horsepower. **Wernher Von Braun,** the chief designer of the Saturn 5, once stated that it was powerful enough to hurl a Volkswagen completely out of the solar system. So effective is the insulation of the liquid-hydrogen and liquid-oxygen fuel tanks (one and one-half inches thick) that ice cubes placed inside them would not melt during a period of several years.

It takes approximately three years to manufacture and assemble the three stages of the Saturn 5/Apollo spacecraft at plants located throughout the United States. The Boeing Aircraft Company assembles the first stage at a plant near New Orleans; the North American Rockwell Corporation builds the second stage in California; and the McDonnell-Douglas Astronautics Company manufactures the third stage at Huntington Beach, California. North American Rockwell assembles the command and service sections of the Apollo spacecraft, and Grumman Aircraft Engineering Corporation at Long Island, New York, builds the lunar landing craft. These components finally come together in Florida at the vertical assembly building of the Kennedy Space Center. This building is more than 50 stories high and is so large that, before it was air conditioned, clouds formed near the ceiling and produced indoor rainfall.

Inside this building, engineers mount the various stages of the spacecraft on a launch platform the size of a baseball diamond. Roughly two months before a scheduled launching, the world's largest doors swing open, and a giant caterpillar-type crawler emerges with a moon rocket 36 stories high and a launch tower for workers. On tracks 10 feet high and 40 feet long, the crawler moves at less than one-half mile per hour to the launch site three and one-half miles away over a road wider than an eight-lane freeway. The moon rocket, launch tower, launch platform, and crawler weigh more than 17 million pounds.

This is the environment of the Aerospace Age—a period of speed and mobility and a time of technological extremes. As a teenager, the middle-aged man of today depended for transportation on his ability to walk, ride his bicycle, or borrow the family automobile. The modern teenager may jump astride his high-speed motorcycle and ride hundreds of miles to vist his girl friend, or he may make the journey in a comfortable late model automobile. No longer is he confined to surface travel, however. He now has at his disposal winged aircraft that fly faster than the speed of sound. He stands at the threshold of space with vehicles capable of reaching the moon and the stars. Just as these vehicles have completely revolutionized his methods of travel, they have also produced major changes in other vital areas of his life. One of America's first aircraft pilots, Charles A. Lindbergh, spoke of these changes in 1969 as follows:

> . . . Probably no devices of science and technology are more responsible than the airplane and the rocket for this revolutionizing of the environment—all life, not only man's. They impinge heavily on the politics, economy, and tempo of all major nations. They have made the remotest corners of the world immediately accessible to commerce, and immediately vulnerable to war. Our profession has helped to remove what was possibly the greatest safeguard to life in aeons past: the buffering effect of relatively slow travel.

SUMMARY

The aerospace environment is an environment of rapidly changing and advancing technology. It is an environment of speed and mobility and changing patterns of life based on high-speed transportation. Man barely becomes familiar with one aerospace achievement before he is confronted with another. In relatively brief periods, he advances rapidly from new age to new age, making yesterday's achievements obsolete today. Modern scientists and technicians view nothing as impossible; their attitude is that anything governed by general physical laws can be achieved with sufficient time, money, and people.

Man's entire existence has been marked by a ceaseless struggle to advance and improve himself. At various times in his history, he has appeared to advance at an accelerated pace, and, at other times, he has made little progress. Historians refer to periods of rapid advancement as great revolutions. So rapid has been man's technical advancement in the present age that it has become known as the aerospace revolution. In a relatively short period, man has gained dominion over an ocean of air in winged aircraft that fly faster than the speed of sound and in spacecraft that carry him at speeds over 20,000 miles per hour to the moon and back. In the process, he not only drew people of the world closer together but completely changed his economic, social, and political traditions.

When the Wright brothers introduced the Air Age, man had spent something like 50,000 years traveling no faster than 35 miles per hour. The airplane gave him the ability to move unhampered over surface barriers at fantastic rates of speed. In slightly over 60 years, the airplane has evolved from the toy of a small group of men considered as cranks in their day to a common transportation medium and a destructive weapon of war. The history of the airplane in its transportation role holds a unique interest of its own. But the technical evolution of winged flight is the story of technical progress in the twentieth century. In a very real sense, the process by which the airplane evolved explains the process of technical change in other areas of modern life. This text traces the story of human flight from the days when man only dreamed of flying like birds to the modern age when he made his first journey to the moon. It is not a history in the usual sense of the word; instead, it shows how technical improvements in aircraft design brought man into the world of aerospace.

WORDS AND PHRASES TO REMEMBER

aeronautics
aerospace vehicles
airbuses
astronautics
high-gravity forces
mach
micrometeoroids
multiengine
suborbital
subsonic
supersonic
transoceanic
variable-sweep wings
winged aircraft

NAMES TO REMEMBER

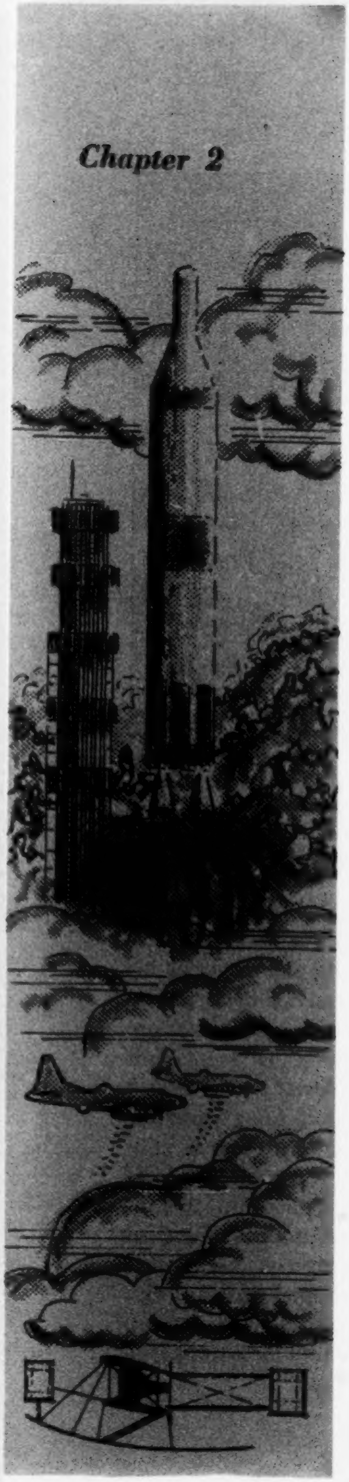
Apollo
Explorer I
Gagarin, Yuri Alekseyevitch
Glenn, John H.
Lindbergh, Charles A.
Project Gemini
Project Mercury
Saturn V/Apollo
Shepard, Alan B.
Sputnik 1
Von Braun, Wernher
Wright brothers

QUESTIONS

1. **What is the role of transportation in a civilized society?**
2. **Discuss some of the most significant characteristics of the Aerospace Age.**
3. **Cite example to show how rapidly aviation has advanced since the Wright brothers introduced the Air Age in 1903.**
4. **What events signalled the coming of the Space Age?**
5. **What was the purpose of projects Mercury and Gemini?**
6. **Show how the Apollo program represents the pinnacle of man's technological achievement.**

THINGS TO DO

1. Make a survey of your community for changes that have come as a result of advancing technology.
2. Find out how many nationally scheduled airlines come into your state. Your state departments of commerce or aeronautics may have maps showing major airports and scheduled airline routes.
3. Write to a major airline company and request pictures of their latest airliners, including interior and exterior photographs.
4. Make a picture collection of US manned and unmanned spacecraft that have been launched since World War II.



Chapter 2

An Age-Old Dream

THIS CHAPTER tells the story of man's earliest efforts to fulfill his age-old dream of flying through the air. It begins with some of ancient man's legends of flight and his attempts to fly by imitating the wing movements of birds. It then describes some of the exploits of pioneer balloonists and the design of their balloons. The chapter traces the evolution of lighter-than-air flight from the first free-floating balloons to the giant dirigibles that carried man on his first scheduled passenger flights. When you have studied this chapter, you should be able to do the following: (1) tell when, how, and by whom the first balloons were invented and explain how they were constructed and operated; (2) describe some of the innovations and experiments that led to steerable balloons and rigid airships; and (3) describe the advances in lighter-than-air flight brought by such men as Count Ferdinand von Zeppelin and Alberto Santos-Dumont.

MAN HAS ALWAYS had the resources necessary for flight at his disposal, but he has not always known how to use them. For something like a half-million years, he lived at the bottom of a vast ocean of air and found little use for it except to breathe. Although he could not see it, he was constantly aware of its presence. He not only inhaled and exhaled it in breathing but also experienced comfort and discomfort as it moved about him. He watched it drive clouds through the skies, sweep gently over grass-covered fields, or violently uproot great trees. Even as he observed the smoke of his campfires drifting upward, the flight of his boomerangs, or the quick movement of the squid, little did he realize that he was witnessing clues to the secret of flight—the action of

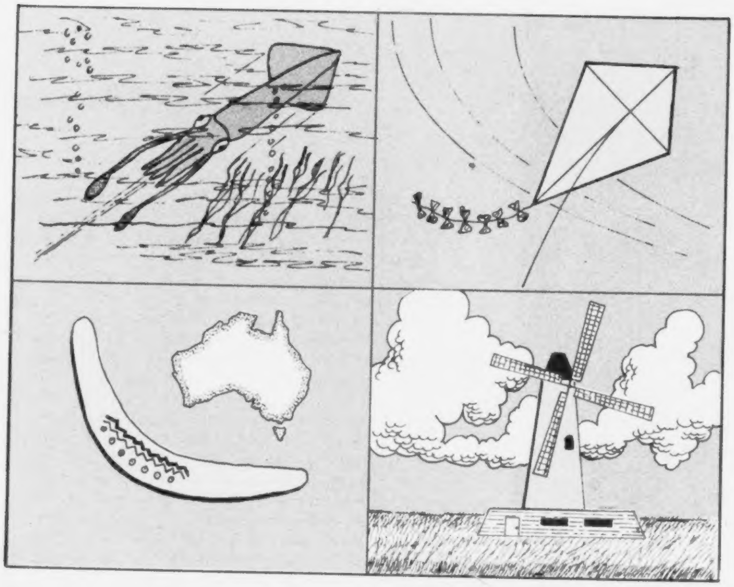


Figure 8. Man used the resources necessary for flight for thousands of years before he appreciated their aeronautical significance.

lighter-than-air substances, air pressure on wing surfaces, and jet propulsion.

For centuries, man created and used a number of devices without realizing their significance in aeronautics (Fig. 8). No one knows exactly when he shot his first feathered arrow into the sky or hurled his first boomerang. But both of these devices depend for their success upon the action of air on their surfaces. Several centuries before Christ, the Chinese applied the helicopter principle in the invention of a flying top. They achieved brief flights with this device by rapidly rotating a lightweight spindle with feathers inserted in it. Long before the Christian era, they had used kites to ward off evil spirits and as military weapons to demoralize their enemies. Chinese legends of the Middle Ages speak of monster kites capable of lifting men into the air. The vertical windmill with its horizontal shaft is a product of ancient Rome. Kites in reality are crude forms of airplanes in the sense that they are supported in the air by the action of wind upon their surfaces. The windmill is obviously a propeller. It was centuries, however, before man recognized the aeronautical principles applied by these devices—

the windmill as a propeller in 1784 and the kite as an airplane wing in 1804.

Although it took thousands of years for man to discover the secret of powered flight, his dream of flying no doubt began when he first observed the graceful flight of birds. Restricted as he was in his ability to move from place to place, he could only gaze in admiration or envy as they soared freely through the ocean of air above him. For centuries, he reasoned that, if birds and other creatures could fly, he could also fly if he had suitable mechanical aids. He made little progress with the problem of flight, however, until the first balloon rose into the air less than 200 years ago. He took even longer to achieve powered flight—not until the first decade of the twentieth century.

THE BEGINNINGS OF HUMAN FLIGHT

Inspired with an impossible dream, man could only endow his gods and other superhuman creatures with the gift of flight. In myth, religion, and legend, he recorded the flights of his heroes, gods, and prophets and even invested himself at times with the power of flight. As celestial voyages and other aerial activities increased, prophets in every land foretold conquest of the air. From myths and legends came the aerial fiction of later years when man began to make imaginary flights through space in giant airships. Still later came the real flight pioneers and adventurers who set out to prove by example man's ability to fly like the birds. Boldly and often foolishly, they equipped themselves with flapping wings and jumped from towers and other high places, frequently to their death or dismemberment. Others contented themselves with drawing sketches of crude flying machines or describing in detailed accounts the possibilities of human flight.

Myths and Legends of Flight

Quite early in the evolution of civilized society, man allowed his imagination to soar when he realized his physical inability to fly. Heaven and earth became the abode of flying demons and dragons, angels and devils, winged horses, and gods with winged sandals. Every civilization had its winged heroes, gods, and demigods. Ancient Persia had its winged bulls guarding the temples of its gods. The Norse gods Thor and Odin and the German Valkyrie descended on wings to battlefields on earth and returned to Valhalla with slain heroes. The Greek god Hermes, also known as the Roman god Mercury, was a messenger god with winged sandals. Bellerophon of Corinth is said to have ridden the winged horse Pegasus when he destroyed a monster from the air endangering the lives of beautiful maidens. Pegasus may have been the world's first dive bomber!

The Chinese claim the first recorded story of man in flight. In the *Annals of the Bamboo Books,* the Emperor Shun as a boy 4,000 years ago donned the wings of a bird to escape from captivity. On another occasion, his father ordered him to the top of a tall granary and then set it afire. The young emperor escaped by floating to the ground with the aid of two wide-brimmed reed hats. He may well have been the first parachutist! Eighteen centuries before Christ, a Chinese god of thunder and lightning sailed through the heavens on a flying chariot. Sixteen hundred years later, a Chinese apothecary gained the power of flight by means of a specially concocted elixir. As he rose above the earth, he dropped his flask in a barnyard, and the animals also took off after sampling the elixir.

According to Persian folklore, an ancient ruler by the name of Kaikaus had a throne pulled through the air by hungry eagles as they flapped their wings to reach meat impaled on spears just beyond their beaks. Other accounts speak of Alexander the Great in a cage drawn through the air by winged griffins. In Europe, Wayland the Smith flew with the aid of a shirt made of feathers. In Africa, an invisible warrior, Kibaga, dropped rocks from the sky on his enemies until they brought him down with arrows shot blindly into the air.

One of the best known flying legends is the Greek story of Daedalus and Icarus, a father and son who escaped from the island of Crete after being imprisoned by King Minos (Fig. 9). To reach the distant island of Sicily, they built wings of feathers and wax. According to the story, Icarus impulsively flew too near the sun; his wings collapsed when the wax melted; and he plunged to his death in the sea below. Modern fliers of course read this legend with amusement because they know that temperature decreases at upper levels of the atmosphere. Rather than extreme heat, Icarus probably would have had the problem of ice formations on his wings. On the other hand, some observers, H. G. Wells for example, believe that this legend may contain an element of reality. Quite possibly, Daedalus built a large glider and took advantage of updrafts from the steep cliffs that rise from the sea in Crete. Icarus may have died in a brave but foolish experiment.

The first concrete expression of man's desire to fly occurred about 400 B.C. when Archytas, a Greek philosopher and disciple of Pythagoras, constructed a wooden pigeon. Although little is known about

Figure 9. Man expressed his desire to fly in myths, legends, and folklore for thousands of years before he discovered the secret of flight.

the details of construction, an obscure Roman historian states that this man-made bird flew by means of "hidden and enclosed air" activated by "some lamp or fire within it." Modern historians believe that Archytas may have suspended his device by wires from a revolving arm turned by steam. At any rate, this ancient dreamer obviously created something more than a kite or hand-propelled toy.

In addition to the myths and legends of flight, fiction writers and story tellers of later years provide still further evidence of man's continuing interest in flying. Roger Bacon, an early British scientist, suggested in 1256 A.D. that the surface of the atmosphere consisted of "liquid fire" or "ethereal air." Bacon proposed two methods of achieving flight. He believed that, if he could obtain "ethereal air," he could enclose it in copper spheres and rise aloft as a cork rises on the surface of water. A second alternative was an instrument with flapping wings for man to use in capturing "liquid fire." A French writer of science fiction, Cyrano de Bergerac, suggested the passage of heated air through a square capsule for a trip to the moon. Edgar Allan Poe, Jules Verne, H. G. Wells, and others wrote detailed accounts of imaginary transoceanic flights, journeys through space to the moon, and orbiting passenger aircraft.

These early accounts of human flight have little if any scientific basis. They are the expressions in legend and in fiction of man's undying urge to fly. Although they are largely imaginary, they were the vehicles by which early man kept alive his longing for wings. They encouraged the will to fly and ultimately led to daring and often foolish exploits by men who believed that they had discovered the secret of human flight. These men were the tower jumpers and the wing flappers whose simple adventures and failures led to searches for the secret in other areas.

Tower Jumpers and Wing Flappers

For thousands of years, man attempted to fly by imitating the flight of birds. He therefore considered the problem of flight only in terms of artificial wings flapped by the movement of his arms and legs. The first accurate report of such a flight occurred in the eleventh century when an unnamed "Saracen of Constantinople" donned a cloak stiffened with willow poles and leaped to his death from the top of a tower. An English monk of the same period also fashioned some wings and flew "more than a furlong" before he broke his legs. He contended that he fell only because he had not attached a tail to his "hinder parts." Five hundred years later, an Italian adventurer named John Damian broke his thigh bone when he attempted to fly from the walls of Stirling Castle.

The most noteworthy of these early aeronauts was **Leonardo da Vinci,** the first scientific pioneer in the field of aviation. Like his contemporaries, however, da Vinci believed that man could fly only by imitating birds in flight, that is, by swimming through the air with flapping arm motions similar to swimmers in water. He was an avid student of birds, and, from his studies, he concluded correctly that the flow of air over a bird's wing provides lift—the faster the flow, the greater the lift. He designed several **ornithopters** or flapping-wing aircraft, believing that he could achieve flight by rowing the wings downwards and backwards in the same manner that birds move their wings (Fig. 10). Da Vinci made two basic mistakes in the design of his ornithopters. Without the benefits of high-speed photography, he did not

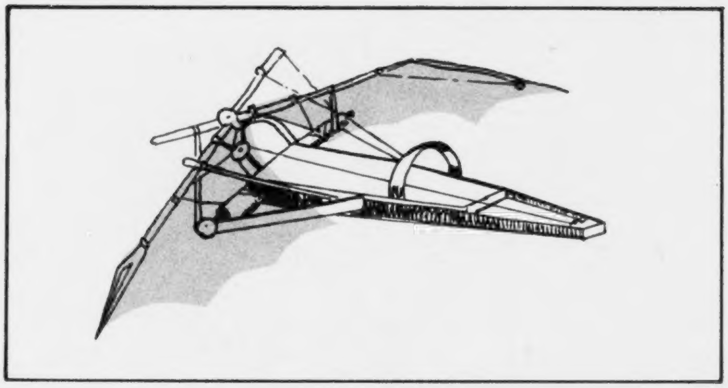


Figure 10. Leonardo da Vinci searched for the secret of flight in a flapping-wing aircraft known as the ornithopter.

recognize that the action of birds' wings in flight involved much more than simple downward and backward strokes. This fact alone made his ornithopter an impractical instrument of flight. He also did not recognize that a man could not generate sufficient muscle power to sustain flight by flapping the wings of his cumbersome machines. Strangely enough, however, a contemporary of da Vinci equipped himself with flapping wings and supposedly made several faltering glides over Lake Trasimeno.

Despite da Vinci's misplaced ingenuity in the design of ornithopters, he did design what would have been practical aviation devices had his works been discovered earlier. For example, his aeronautical notes contain a marginal sketch of a pyramidal-shaped parachute that would enable a man to "throw himself down from any great height without sustaining any injury." He also designed and flew a small helicopter equipped with a crude form of **airscrew** (aircraft propeller) that operated from some sort of spring mechanism. Although da Vinci kept voluminous notes on his experiments with air and centers of gravity, his works did not become known until the latter part of the nineteenth century when **aerodynamics*** had already become an exact science.

With increasing numbers of wing-flappers jumping to their death, it became obvious that muscle power would never be sufficient to sustain man in flight. Progress in heavier-than-air flight suffered a serious set-

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* That field of dynamics concerned with the motion of air and other gaseous fluids, or of forces acting on bodies in motion relative to such fluids.

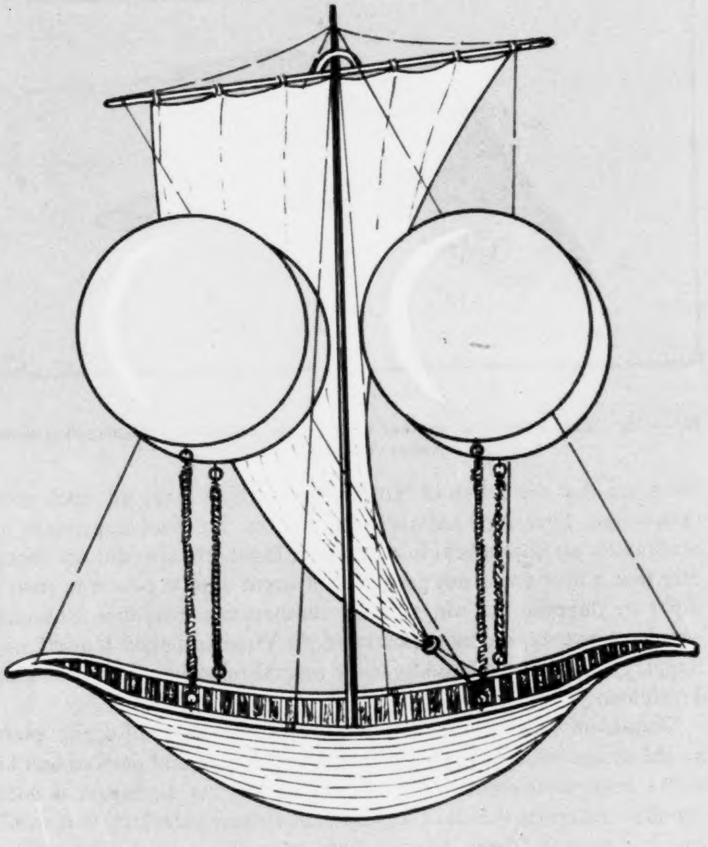

Figure 11. Francesco de Lana's vacuum-balloon airship.

back when G. A. Borelli, an Italian scientist, gave a forceful demonstration in 1680 to prove that man's pectoral and leg muscles were too weak to carry his weight through the air. Borelli stated: "It is impossible that men should be able to fly craftily by their own strength." He concluded that he had "no faith in any invention designed to lift man from the earth." Other distinguished men of his day agreed with him, and heavier-than-air flight was virtually abandoned for the next 100 years.

Flying enthusiasts turned next to the possibilities of lighter-than-air flight in devices that would float through the air like clouds. In the mid-seventeenth century, a Jesuit priest, **Francesco de Lana,** proposed an aerial ship consisting of a small boat suspended from four thin copper globes, each 20 feet in diameter. By forcing the air from these globes, de Lana maintained that he could create a lighter-than-air vacuum capable of lifting his ship into the air (Fig. 11). De Lana was the first man to point out the principles of aerostation (lighter-than-air flight). His theory was that evacuated globes would be lighter than the surrounding air and would therefore provide the buoyancy necessary to sustain flight. De Lana proposed to control his flight by carrying **ballast*** to govern his rate of climb and readmitting air into his globes to descend. He failed to recognize, however, that his globes would have collapsed under the weight of the outside air. De Lana refused to allow construction of his ship because of a prophetic belief concerning its possible role in war. "Where is the man," he said, "who can fail to see that no city would be proof against surprise . . . iron weights could be hurled to wreck ships at sea, or they could be set on fire by fire balls and bombs; nor ships alone, but houses, fortresses and cities could be thus destroyed, with the certainty that the airship could come to no harm as the missiles could be hurled from a vast height."

LIGHTER-THAN-AIR FLIGHT

The evolution of human flight followed two broad paths of development generally referred to as lighter-than-air and heavier-than-air flight. In terms of scientific principles applied to achieve the vertical force or lift essential to all flight, more appropriate references are buoyant and kinetic flight. **Buoyant flight** is the floating action of an object in the air; **kinetic flight** depends upon the relative motion between an aircraft and the air. Both types of flight operate on the fundamental principle that air has mass. In contrast to kinetic flight, buoyant flight applies a principle established by Archimedes in 250 B.C., regarding the upward force that acts on a body immersed in fluid.

According to this principle, a body immersed in a liquid experiences an upward force equal to the weight of the fluid which it displaces. In other words, the weight of one cubic foot of water is 62½ pounds. If a solid cube having a volume of 1 cubic foot is placed in water, it will be acted upon by an upward force or lift of about 62½ pounds. Archimedes weighed a cubic foot of water, a cubic foot of wood, and a cubic foot of iron. He found that a cubic foot of wood is lighter than a cubic foot of water and that a cubic foot of iron is heavier. Therefore, a cubic foot of wood submerged in a cubic foot of water will rise in the water until the weight of its submerged part equals the weight of the water that it displaces. Archimedes reached a conclusion long taken for granted by modern man that an object will float if it is lighter than a like measure of water and sink if it is heavier. He reasoned further that, if objects lighter than water will float on the surface of water, then objects lighter than air will float on the surface of the atmosphere. Since air at the earth's surface is approximately 800 times lighter than sea water, any object, such as a balloon or airship, will experience an upward force into the air similar to the force exerted on an object lighter than water. The problem, of course, was to design an object lighter than a like volume of air.

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* Something heavy as sand or water put into the car of a balloon to be thrown out if necessary to reduce the load.

The Montgolfier Brothers

Following de Lana's proposal for a lighter-than-air craft, more than 100 years passed before any further advances were made in man's efforts to achieve mechanical flight. Then, in the late eighteenth century at Annonay, France, about one month after the surrender of Cornwallis to Gen George Washington at Yorktown, **Joseph** and **Etienne Montgolfier** achieved man's first practical victory over the force of gravity. After centuries of speculation on the possibilities of mechanical flight, man suddenly discovered through chemistry that he could fly.

The Montgolfiers were partners in papermaking and were avid readers in popular science subjects of their day, especially subjects concerning the atmosphere. They were familiar with the "inflammable gas" called hydrogen invented by Henry Cavendish. They had tried to enclose this gas in various containers, but it tended to seep too rapidly through paper, linen, and silk to be of any practical use in aerial navigation. One day while observing smoke and sparks rise upward from his fireplace, Joseph reasoned that a bag filled with smoke should also rise. He believed that, by capturing the gas or whatever it was that lifted the smoke and sparks, he could use it to lift other things. Undoubtedly, smoke must contain a gas similar to hydrogen but different because it might be enclosed in a bag. If, like clouds, smoke floats in the air, why not use it to make a bag float? He burned paper beneath an oblong silk bag opened at the bottom, and, to his surprise, it rose immediately to the ceiling of his room.

Joseph and Etienne repeated the experiment out of doors with a larger bag which rose to a height of about 70 feet before losing its buoyance. A second "balloon" sailed to a height over 1,000 feet and descended gently almost a mile away. By now, the brothers were convinced that smoke was the secret of their success. After experimenting with various kinds of smoke, they decided that the thick yellow smoke produced by burning wet straw and chopped wool had the greatest upward lift. It did not occur to them that the weight of the heated air in their bags was about half that of a similar volume of outside air. They did not understand that the bags contained less air because it had been expanded by heat. They thought that smoke alone had provided buoyancy.

Confident that they had discovered the secret of flight, the Montgolfiers arranged a public demonstration of a huge paper-lined linen balloon with a circumference of more than 100 feet. On 4 June 1783 in the public square of Annonay, they suspended their balloon on poles over a great pit filled with fire. As hot air and smoke entered the bag, it swelled to a full 38 feet in diameter and tugged violently at its ground ropes. When Joseph finally gave the release signal, the balloon soared majestically to an altitude of 6,000 feet and drifted for more than a mile before the air cooled and forced a landing (Fig. 12).

The same year saw two additional flights of Montgolfier hot-air balloons. At the summons of King Louis XVI and Marie Antoinette on 19 September 1783, the Montgolfiers staged a second demonstration. For this test flight, they included passengers (a sheep, a rooster, and a duck) in a wicker cage suspended beneath the balloon to determine whether the upper air would sustain life. This balloon rose to a height of about 1,500 feet and, after a flight of about eight minutes, landed in a plot of woods about two miles away. Although the rooster suffered a broken wing when the sheep stepped on it, the first aerial passengers were unharmed by the flight itself. The first man to reach the balloon was a young physician, Jean-Francois Pilatre de Rozier, who in a few weeks would be the first balloon pilot in history.

Convinced that the upper air could sustain life, the Montgolfiers constructed a second giant balloon capable of carrying human passengers and a fire to generate a constant supply of hot air. This balloon measured 74 feet from top to bottom and 48 feet in diameter. At the bottom of the balloon was a circular gallery with wicker rails to carry

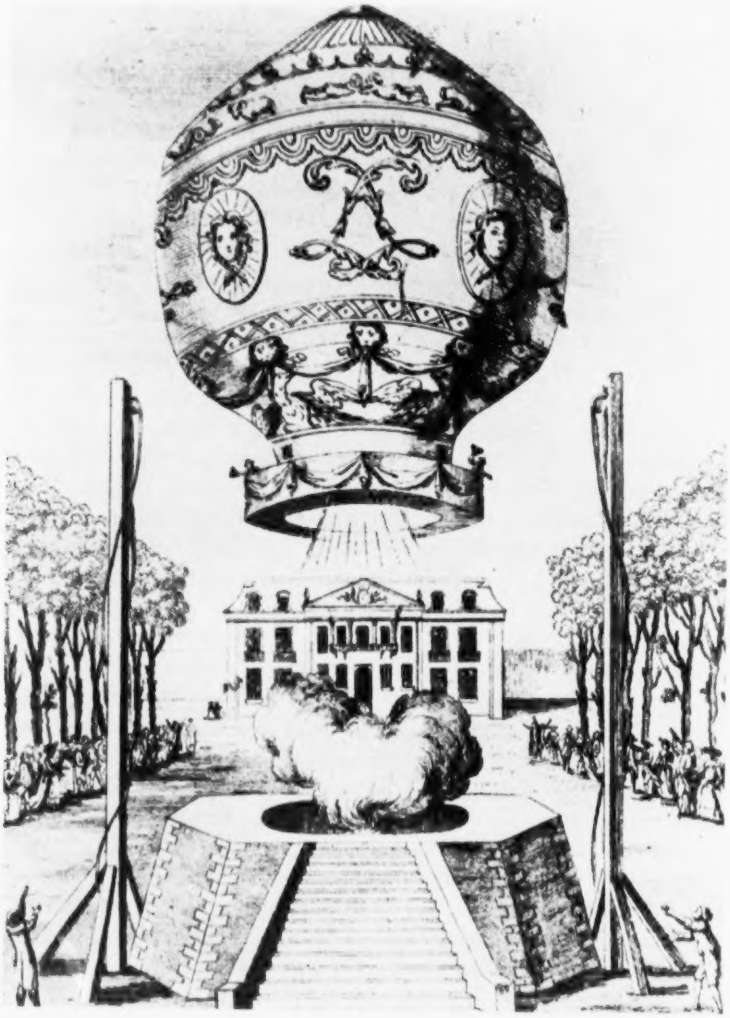

Figure 12. A Montgolfier hot-air balloon over Annonay, France in 1783.

a two-man crew. A brazier hung under the gallery to provide a means of heating air and maintaining buoyancy. Compared with the sophisticated air and space vehicles of modern man, this flimsy linen and paper balloon with a blazing fire beneath it and no directional control was indeed a risky transportation medium. Then, as now, the reward was the adventure of flight and the acclaim of onlookers.

In November, after making several tethered ascents, the youthful de Rozier and the Marquis D'Arlandes climbed into the gallery for the first free flight of a man-carrying balloon. They stoked the fire in the brazier and "at fifty-four minutes past one o'clock passed safely over some high trees and ascended calmly and majestically into the atmosphere." Shortly after the balloon left its moorage, flames from the brazier scorched holes in the balloon, but de Rozier and D'Arlandes met this emergency with wet sponges. The balloon rose to a height of 3,000 feet and carried its passengers more than five miles across Paris before landing 25 minutes later.

News of the Montgolfier brothers' achievements spread rapidly throughout Europe and North America as newspapers spoke of men traveling in a world where only eagles flew. Despite their initial success, however, the Montgolfier balloons were not the final answer to the problem of human flight. In the first place, they could remain afloat only with a constant supply of hot air. Since each balloon had to carry some form of airborne firepot, there was always the danger of fire. Sustained flight in a Montgolfier or hot-air balloon for long periods was obviously impossible. In the second place, these early Montgolfiers were always subject to the vagaries of the wind and had no means of mechanical control except up or down.

Gas-Filled Balloons and Practical Parachutes

So intrigued was the French Academy of Science with the Montgolfiers' accomplishment that it opened a subscription in Paris for a scientific investigation. The learned members of this distinguished organization could not understand how the search of centuries had suddenly been fulfilled by mere amateurs. They engaged an outstanding physicist of the day, **J. A. C. Charles,** a man now known chiefly for his work on the properties of gases. From the first, Charles fully understood the secret of the Montgolfiers' success—the reduced density of the hot air inside their balloons. This in turn suggested the use of hydrogen, a light gas with a weight of 5.3 pounds per 1,000 cubic feet as compared with the 76 pounds per 1,000 cubic feet for air. Two scientists had experimented earlier with hydrogen-filled balloons and had failed because they had used material in their balloon envelope too porous to contain hydrogen. With the help of the Robert brothers who had developed a method of dissolving rubber, Charles constructed a rubberized silk balloon 13 feet in diameter and filled it with hydrogen gas.

He launched his balloon through a "copious shower of rain" on the afternoon of 27 August 1783, less than three months after the first ascension of a Montgolfier balloon. A group of onlookers gasped with amazement as the balloon quickly disappeared at a height of 3,000 feet. Among the spectators was Benjamin Franklin, to whom one cynic remarked, "What use is it?" Franklin's reply was, "What use is a newborn baby?" Also among the spectators was Etienne Montgolfier, who protested to the Academy of Science that its experiment with a dangerous gas would bring fire and ruin to the countryside. One hour later, the balloon did burst about 20 miles from Paris over the village of Goneese. French farmers stood aghast as the mysterious object dropped from the sky, spewing sulphurous gas like some evil dragon. As it bounced over the ground, monks made the sign of the Cross, while the farmers attacked it with their pitchforks. Only after they found a note by Professor Charles on the bottom of the balloon did they return it to Paris.

In December 1783, a crowd of more than 50,000 people saw Charles and one of the Robert brothers make the first flight of a manned hydrogen balloon. From the beginning, the superiority of the hydrogen balloon over the hot-air balloon was obvious. The Montgolfier balloon required constant attention to keep it supplied with hot air; the Charles balloon, or Charliere as it became known, remained airborne for two hours with little effort from the crew. This balloon had a rubberized silk envelope about 27 feet in diameter. Its flight covered a distance of 27 miles at a height of about 2,000 feet. Later, Charles made a solo flight to an altitude of about two miles, discovering in the process that man could ascend only so high before he became subject to pain and possible death.

For all practical purposes, Charles introduced in this balloon the details of construction and operation that were to endure for the next 150 years, i.e., until new ideas and material made it possible to design stratospheric balloons. For example, Charles determined mathematically the amount of hydrogen that his balloon would take without bursting. He suspended the passenger car from a hoop secured by a network of ropes that passed over the top of the balloon. For emergency use, he added an overhead gas escape valve operated by a rope to permit the balloon to descend rapidly. He carried 20-pound bags of sand for ballast and a grapnel (anchor) tied to the end of a rope for landing.

The impact of the Montgolfier and Charles flights on the public was immediate and spontaneous. People throughout the world suddenly became aware of an ocean of air two miles high waiting for exploration. Monarchs demanded explanations of the "new science of aerostation," and the balloon shape caught the fancy of people of all ages. In a period of about two years, people in the United States and Europe saw as many as 40 successful balloon flights. Balloons and balloon shapes appeared in science fiction, on toy counters, on handkerchiefs, dresses, and chinaware, and even on snuffboxes. A favorite sport of the day was to make homemade balloons, fill them with hydrogen, and watch them float away. Many people viewed the balloon as a new and revolutionary transportation medium. George Washington wrote: "Our friends in Paris, in a little time, will come flying thro' the air instead of ploughing the ocean to get to America." Benjamin Franklin dreamed of tying his horse to a balloon and making giant leaps over hedges and ditches. In a more serious vein, he demonstrated remarkable insight when he stated: "Since man may be supported in the air, nothing is wanted but some slight handy instruments to steer and direct motion."

For the next several years, the history of ballooning is the story of man floating through the air in larger balloons for longer distances. Despite increases in size and floating power, however, balloons still had no dependable controls and relied primarily on wind currents. In a flight across the English Channel in 1785, an American physician, Dr. Jeffries, and a French aeronaut, Blanchard, attempted to master the wind with a pair of silk-covered oars and a hand-operated fan, but to no avail. In the face of strong downdrafts, they cast everything overboard—food, navigating equipment, oars, fan, and even Blanchard's trousers. Just as they were about to strike the water, a strong wind carried them over the French coast where they halted their flight by snatching at treetops.

In succeeding years, other balloonists added features that made for safer and more comfortable flights. In 1821, for example, **Charles Green** constructed the *Great Nassau,* a giant balloon of 85,000 cubic feet, and inflated it with coal gas tapped from a city gas main. Green created a kind of automatic ballast with a trailing guide rope. This rope not only regulated the lift of his balloon but also warned the balloonist of rising terrain. One of the largest balloons of the period was *Le Geant,* a gas-filled balloon with a capacity of 200,000 cubic feet. This balloon carried a large two-story car with a capacity for 13 passengers. **John Wise,** the American counterpart of Charles Green, invented the ripping panel, a device for rapid deflation after landing to prevent dangerous dragging over rough terrain. Ballooning also led to the development of the first parachute with modern **configurations** (arrangements of parts). A French aeronaut, **Andre-Jacques Garnerin,** made the first live parachute drop in 1797 from a balloon flying at an altitude of more than 3,000 feet. Early parachutes were relatively safe, but, like balloons, they could not be controlled in wind currents. Jumpers almost without exception suffered from nausea caused by wild side to side motions as they descended. Eventually, vents in the crown of parachutes allowed air to escape, and this provided a stabilizing effect.

Although a majority of early balloon flights were made solely for the adventure of flying, balloons also came to be used extensively for experimental purposes. With his first ascent, Professor Charles made scientific studies of air temperature and barometric pressure at various heights. Jeffries and Blanchard carried meteorological instruments to study air temperature, pressure, and humidity. And, in subsequent years, scientists used balloons to study variations in the earth's magnetic field at high altitudes. A British scientist, James Glaisher, made a total of 28 balloon flights between the years 1862 and 1886, conducting experiments on behalf of the British Association for the Advancement of Science. On one flight, he rose at the rate of 1,000 feet per minute to a height of 25,000 feet and lost consciousness through a lack of oxygen. Thirteen minutes later, he recovered to find his balloon descending at the rate of 2,000 feet per minute. He estimated that he had reached a height of 37,000 feet, the highest that any man had ever been.

Beginning in the mid-1800s and continuing through World War II, balloons played a variety of roles in the conduct of military operations. Balloons appeared as bomb-carrying devices for the first time in 1849 over Venice, Italy, but changes in wind direction forced them back to their launching points. During the American Civil War, **Thaddeus S. C. Lowe** organized a balloon corps to observe the movements of Confederate troops. Although the balloonists furnished valuable information to Union commanders, Lowe finally disbanded the corps for lack of men and financial support (Fig. 13). Balloons were used extensively for observation and reconnaissance during the Franco-Prussian War and the two world wars. Also, in both world wars, large numbers of tethered balloons were used to protect industrial and military centers from air attacks. Despite these limited uses, however, balloons still

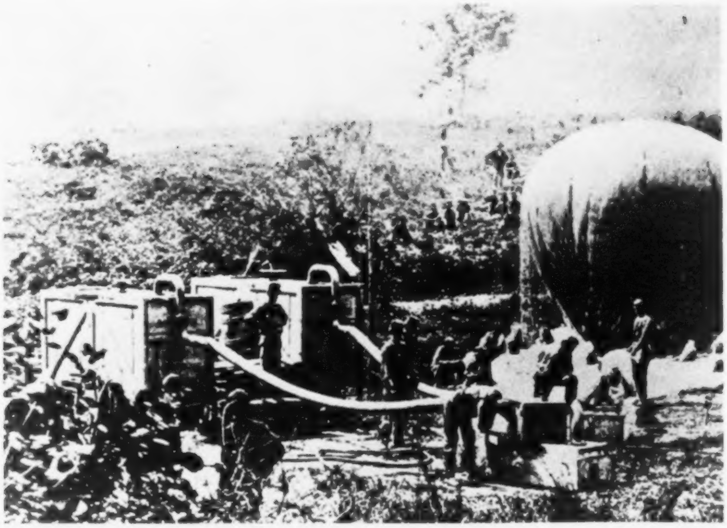

Figure 13. One of Thaddeus S. C. Lowe's balloons being inflated to observe Confederate troop movements during the Civil War.

were largely at the mercy of prevailing winds and, therefore, were impractical transportation media.

Controlled Balloon Flight

As mentioned earlier, balloonists made numerous attempts to develop some means of controlling their flights, but they were severely handicapped because they had no engines for propulsion. Sails were out of the question, and human effort could not provide enough thrust to justify the use of oars. As early as 1784, a French general, **J. B. M. Meusnier,** suggested a change from the spherical to the **ellipsoidal** (elongated) balloon as a means of reducing the resistance of air. No one knows whether Meusnier's design came from his experience with ships or his observations of fish. Though not recognized at the time, it was the initial step toward the huge streamlined dirigibles of a century later.

Meusnier suggested a car in the shape of a boat attached to the balloon by a system of rigging to prevent lateral swinging movements. For sustained flight, he recognized the need to maintain the shape of his balloon after he expelled hydrogen to control altitude. He proposed an envelope of several compartments, some filled with hydrogen and

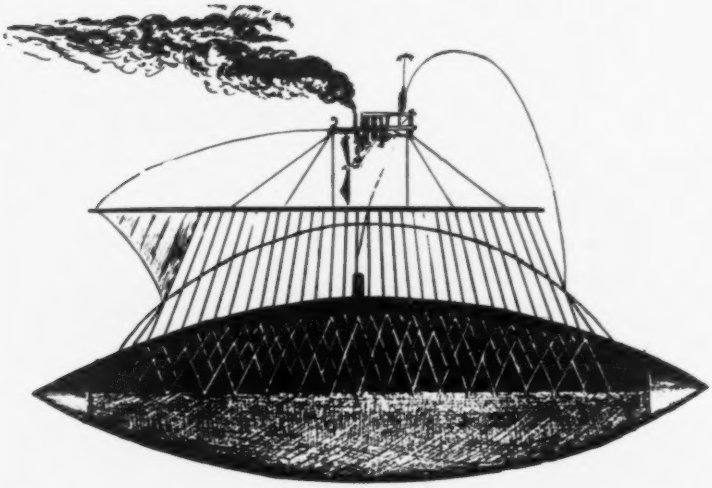

Figure 14. A steerable balloon designed by Henri Giffard in 1852.

some with air. By pumping air into or out of the compartments, he could maintain a constant volume inside the balloon and, at the same time, adapt to changes in buoyancy. The most impractical part of his design was that he intended to drive his airship with three screw-propellers operated by a crew of 80 men. If an engine had been available, there is little doubt that his airship would have equalled the nonrigid dirigibles of the late 1800s.

Not until 1852, however, did man achieve his first success in steering a balloon. Another Frenchman, **Henri Giffard,** built a cigar-shaped airship 144 feet long and 39 feet in diameter, driven by a three-horsepower steam engine. The engine alone weighed only 110 pounds, but, with its boiler and an hour's supply of fuel and water, it weighed 460 pounds. The car hung from a long horizontal pole carried by rope rigging from a net that passed over the envelope of the balloon. At one end of the pole or keel, Giffard attached a triangular vertical sail to serve as the rudder (Fig. 14). Early on the morning of 24 September 1852, he donned a checkered silk vest and a stovepipe hat and entered his steam-driven airship for its first test flight. Under a full head of steam, the engine started the huge propeller spinning with a heavy roar, and Giffard rose into the air to the cheers of a great crowd of people. He chugged over Paris at a speed of about 5 miles per hour and finally reached Trappe, 17 miles away. When he attempted to return to his starting point, he found that his engine did not have sufficient power to overcome a strong wind. After remaining aloft all night, he landed successfully the next morning to the acclaims of a jubilant press that saluted him as "the Robert Fulton of the air." He was the forerunner of the **dirigible,** an airship that could be directed, controlled, and steered from takeoff to landing.

Although Meusnier and Giffard paved the way for future designers of airships, it was almost 100 years before any further significant advances were made in flying. Despite Giffard's initial success with a powered airship, his engine was far too heavy for operational use. Successful powered flight depended upon the development of a lightweight engine with sufficient power to overcome wind resistance. What appeared to be a significant advance came in 1872 when a German engineer, **Paul Hanlein,** built an airship 164 feet long and equipped it with a four-cylinder gasoline engine—the first known **internal combustion engine*** used in an aircraft. Using coal gas taken from the balloon envelope, this engine generated 3.6 horsepower and weighed approximately 205 pounds per horsepower. Not only did the weight of the engine reduce initial lift, but lift also decreased during a journey as the engine consumed gas from the balloon. Hanlein achieved speeds up to 10 miles per hour on test runs, but he had to discontinue his experiments for lack of funds.

Another airship, *La France,* constructed by **C. Renard** and **A. C. Krebs** carried a nine-horsepower electric motor that operated from specially designed batteries and drove a **tractor propeller**** 23 feet in diameter. Although the complete power plant weighed 130 pounds per horsepower, *La France* reached speeds of 14 miles per hour, a definite improvement in engine performance. Like her predecessors, however, *La France* was limited by her electrical propulsion system. Sufficient batteries to generate power for any length of time added excessive weight.

The first rigid airship appeared in 1897 when an Austrian **David Schwarz** built a balloon envelope of sheet aluminum eight thousandths of an inch thick, secured to a tubular aluminum frame. A 12-horsepower gasoline engine drove two aluminum propellers, one on each side of the hull which was 154 feet long. On its maiden flight, this airship reached a speed of 16 miles per hour, but it was completely demolished four miles from its starting point when it was forced to land by mechanical troubles, leaking gas, and bad weather. Like other engines of the day, Schwarz's engine generated too little power for its weight and size.

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* Any engine in which the pressure of gases formed by combustion or fuel is directly used to give the engine motion.

** A propeller that pulls rather than pushes an airplane through the air.

For almost a century, progress in airship development lagged simply because engine design had not kept pace. It was impossible not only to build practical airships but also to solve practical problems associated with airships in flight. Further progress in flying came only after internal combustion engines reached an advanced stage of development in the early part of the twentieth century.

Nonrigid and Rigid Dirigibles

Controlled powered flight of lighter-than-air vehicles became possible when the spherical balloon changed to the elongated or ellipsoidal nonrigid airship or dirigible. Although this type of airship was a significant step in man's ability to fly, it had serious limitations as a practical transportation medium. Its shape could be maintained only by internal gas pressure, and internal pressure always had to exceed atmospheric pressure by a margin that varied according to speed and load. Otherwise, the balloon envelope would either buckle under the pressure of external forces or become severely distorted. These difficulties, of course, increased with the size of the balloon and, for years, limited nonrigid balloons to a capacity of about 500,000 cubic feet.

As balloon technology advanced, however, balloon envelopes were stiffened by rigid keels and became known as semirigids. The keels of these airships extended along most of the length of the envelope and carried the loads consisting of engines and passengers. Giffard suspended his keel below the balloon envelope and secured it by means of rigging. His balloon and others of his day were not semirigid in the strict sense because they had external keels over only a part of their total length. The true semirigids carried their keels inside their envelopes from end to end.

As a practical flying machine, the dirigible made its most noteworthy advances with the contributions of Count **Ferdinand von Zeppelin** in Germany and **Alberto Santos-Dumont,** a wealthy Brazilian of French descent. Both men successfully used internal combustion engines to power lighter-than-air craft. Although von Zeppelin perfected the dirigible for public use, it was Santos-Dumont who ushered in the era of the powered gas bag. His first nonrigid airship was a small vessel 82 feet long, driven by a three-horsepower gasoline motor. On its first flight, it reached a height of 1,300 feet and responded readily to movements of its rudder. During this period between 1898 and 1907, he constructed and flew 14 gasoline-powered nonrigid airships. On his largest vessel of 157 feet, he used a 20-horsepower engine, and, on another, he carried an engine that developed 60 horsepower. He became the idol of Paris in 1901, when he piloted a blimp driven by a 12-horsepower motor from St. Cloud around the Eiffel Tower, a distance of nine miles. Despite a side wind of 12 to 13 miles per hour, he developed a speed of 19 miles per hour and covered the distance in less than one-half hour. About the time that he completed his fourteenth airship, Santos-Dumont became interested in the winged flights of the Wright brothers in the United States. He abandoned the airship altogether and followed the attraction of this new development in air travel. He would later make his mark as one of the pioneers of winged flight.

Meanwhile, dirigibles continued to grow in size and efficiency, particularly in France, Germany, and Italy. One of the most significant advances came during the early decades of the twentieth century with the development of the rigid airship. This was the age when giant, torpedo-shaped dirigibles began making regularly scheduled passenger flights and establishing world distance records. For the first 25 years of this century, people considered the terms rigid airship and Zeppelin virtually synonymous because of Count von Zeppelin's pioneering work. Zeppelin began his first experimental dirigible in a floating shed on Lake Constance, Germany. Extremely large for the time, this ship took the form of a relatively slender cylinder, 420 feet in length and 38 feet in diameter, with a rounded nose and pointed stern.

Although the giant dirigibles represented a step forward in man's ability to fly, they were at best a risky form of travel. Improved engine and propeller design brought sustained flight and controllability, but hydrogen was just as explosive as ever. Even with helium gas used in United States dirigibles, disaster seemed always at hand. The size of these airships and the volume of gas needed to keep them afloat made them vulnerable targets for storms and high winds. More than half of the Zeppelin dirigibles built in 1914 came to violent ends either by explosions, engine failures, or crashes caused by windstorms. One of the most successful rigid dirigibles was the **Graf Zeppelin,** launched at Friedrichshafen, Germany, in September 1928. This remarkable airship inspired widespread interest in the possibilities of regular passenger service in Germany, the United States, and Great Britain.

The Graf Zeppelin was larger than any of its predecessors—772 feet long and 100 feet in diameter with a volume of 3,710,000 cubic feet. Its framework was made of **duralumin,** a strong, lightweight alloy of aluminum with copper, manganese, magnesium, and silicon. Five 530-horsepower engines gave the dirigible a top speed of 80 miles per hour. Passenger accommodations included a dining room, sleeping compartments, and a saloon in the rear of a gondola attached to the hull. In the front of the gondola was the control position, navigating cabin, and a radio compartment. Wind-driven generators provided electric power for lighting and heating.

On its maiden flight, the Graf Zeppelin flew from Friedrichshafen, Germany, to Lakehurst, New Jersey, a distance of 3,971 miles, in about 4½ days. It made the return trip in about 3 days and established a world airship record, unbroken to this day, for distance in a straight line without landing. In 1929, it made a round-the-world flight, a distance of about 20,500 miles during a period of three weeks. With these outstanding successes by 1930, it began regularly scheduled passenger and mail service across the Atlantic from Germany to South America, continuing each summer without mishap until 1937. It covered more than one million miles and carried approximately 13,000 passengers.

Encouraged by the achievements of the Graf Zeppelin, the United States, Great Britain, and France constructed airships based on the Zeppelin design, but, after a series of disasters, all three countries lost interest in dirigibles as passenger aircraft. Germany continued to build Zeppelins and, in 1936, launched the **Hindenburg,** the world's largest airship (Fig. 15). It was 803 feet long with a maximum diameter of 135 feet and a volume of more than 7 million cubic feet (almost twice that of the Graf Zeppelin). On 3 May 1937, it left Germany with 97 passengers for its first transatlantic crossing of the year to North America. As it approached its mooring at Lakehurst, New Jersey, three days later, it suddenly burst into flames and within seconds became a raging inferno. Thirty-six people lost their lives, and numerous survivors suffered horrible burns. The exact cause of this disaster is an unsolved mystery, but an inquiry established the probable cause as leaking hydrogen ignited either by static electricity or lightning. The destruction of the Hindenburg brought an end to the era of passenger-carrying dirigibles. Today, dirigibles survive primarily as small nonrigid airships used for advertising purposes.

After thousands of years, buoyant or lighter-than-air vehicles finally provided man with at least a partial fulfillment of his age-old desire to

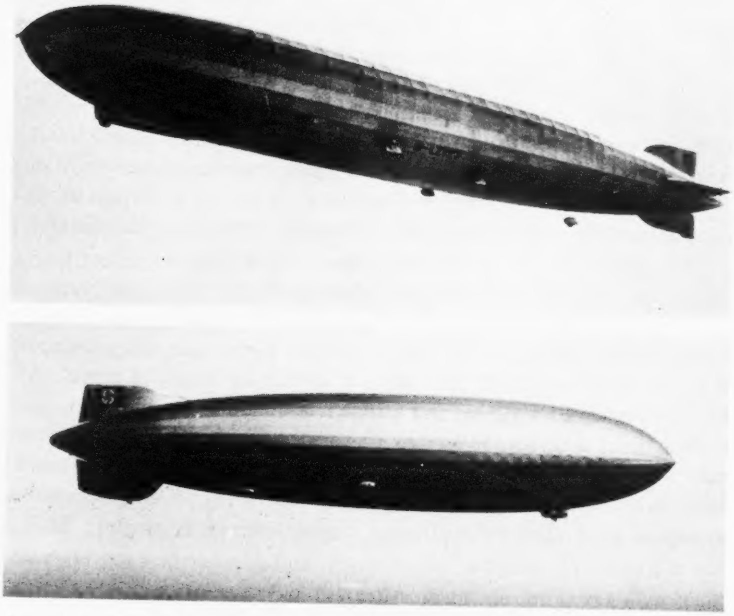


Figure 15. The Graf Zeppelin and the Hindenburg were two famous dirigibles that made regularly scheduled transatlantic flights.

fly. With a "cloud" enclosed in a bag, he created worldwide airmindedness and acquired new knowledge that would ultimately lead to even greater achievements in winged flight. Balloons and dirigibles freed him from his bondage to the earth, but they wrote a conflicting record of achievement and disaster that left buoyant flight with a past but no future. He still had to create a mechanical device sufficiently reliable to overcome nature's moods.

SUMMARY

For centuries, man could only dream of flying as he watched the birds soar with no apparent effort through the skies above him. Realizing his own inability to fly, he vested his gods and other superhuman creatures with the gift of flight. In myth and legend, he described in detail the flights of his favorite deities and heroes. Not until he sent gas-filled balloons into the air less than 200 years ago did he make any progress in mechanical flight. He did not achieve powered flight until the first decade of the twentieth century.

Human flight followed two broad paths of development generally known as lighter-than-air and heavier-than-air flight. The first lighter-than-air flight came with the smoke-filled balloons of the Montgolfier brothers in 1783 and with the hydrogen balloons of J.A.C. Charles in the same year. Although balloons provided the means for man to float through the air, they were always at the mercy of the wind and other natural phenomena. Despite numerous attempts to develop some means of control, balloonists were for the most part unsuccessful until the spherical balloon advanced to the ellipsoidal dirigible.

The giant dirigibles of the early twentieth century represent man's most significant advances in lighter-than-air flight. With these giants of early air travel, man not only established world flight records but also learned much that he could apply to winged flight. Like other forms of buoyant flight, however, they were at best risky forms of travel. Although improved engines and propellers made sustained and controlled flight a reality, hydrogen was just as explosive as ever. Even after helium gas replaced hydrogen, disaster seemed always at hand. With the exception of the Graf Zeppelin, practically all dirigibles came to violent ends either by explosions, engine failures, or crashes. Theirs was a conflicting record of achievement and disaster that left buoyant flight with a past but no future. Man still had to create a reliable flying machine.

WORDS AND PHRASES TO REMEMBER

aerodynamics
airscrew
ballast
buoyant flight
configuration
dirigible
duralumin
ellipsoidal
internal combustion engine
kinetic flight
lift
ornithopter
tractor propeller

NAMES TO REMEMBER

Charles, J. A. C.
Da Vinci, Leonardo
De Lana, Francesco
Garnerin, Andre-Jacques
Giffard, Henri
Graf Zeppelin
Green, Charles
Hanlein, Paul
Hindenburg
Krebs, A. C.
Lowe, Thaddeus S. C.
Meusnier, J. B. M.

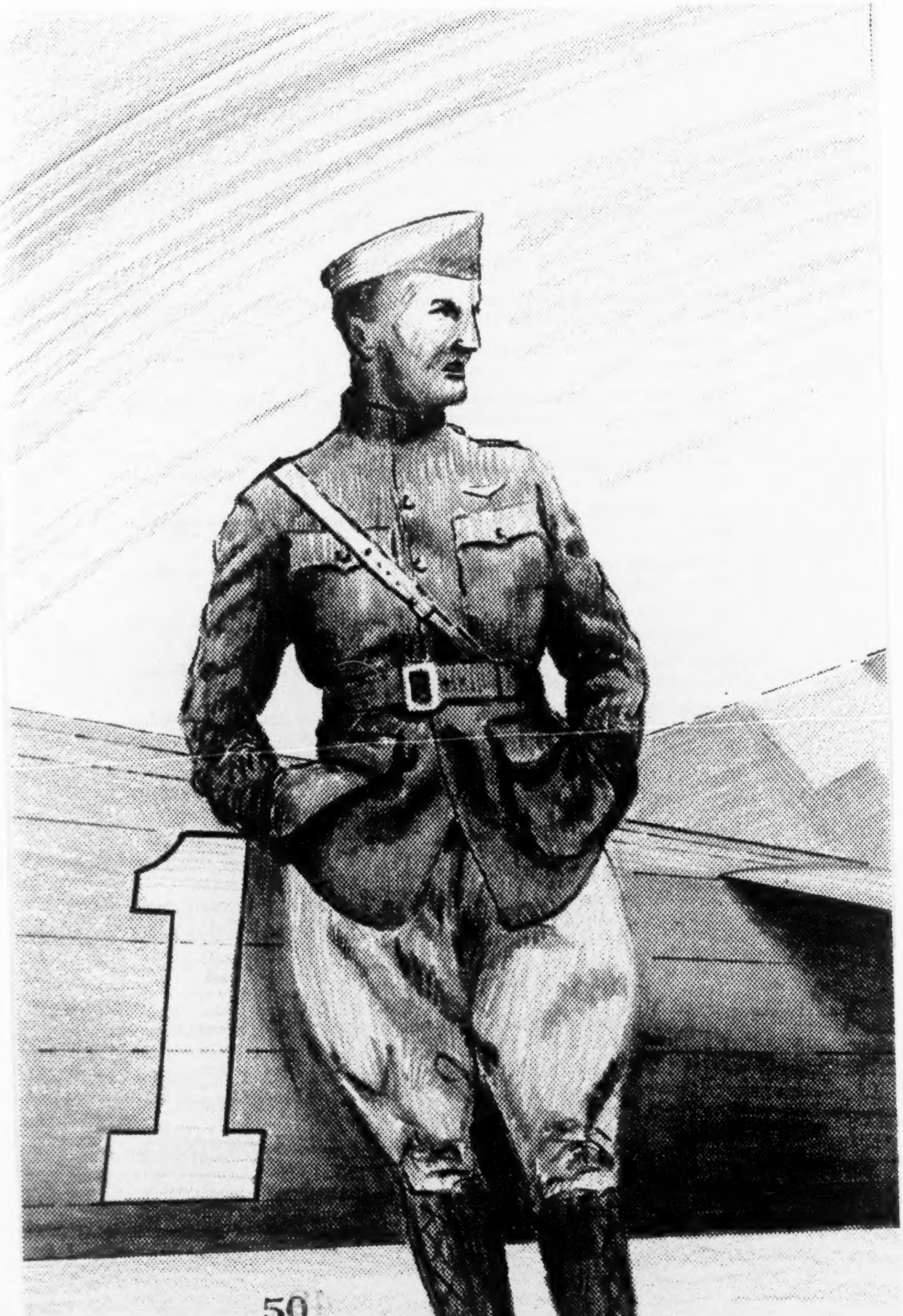
Montgolfier, Joseph and Etienne
Renard, C.
Santos-Dumont, Alberto
Schwarz, David
Von Zeppelin, Count Ferdinand
Wise, John

QUESTIONS

1. **What were some of the resources used by early man before he recognized their significance in aeronautics?**
2. **How did early man compensate for his inability to fly? Discuss some of the legends that gave expression to man's desire to fly.**
3. **What were the contributions made by such men as Leonardo da Vinci and Francesco de Lana to aeronautical science?**
4. **What is the difference between buoyant and kinetic flight? How does buoyant flight apply to a basic principle established by Archimedes in 250 B.C.?**
5. **Describe the achievements of the Montgolfier brothers in lighter-than-air flight.**
6. **What specific improvements did J.A.C. Charles introduce in the construction of balloons?**
7. **Describe the impact of early balloon flights on the public and such men as Benjamin Franklin and George Washington.**
8. **What contributions did Charles Green, John Wise, and Andre-Jacques Garnerin make to lighter-than-air flight?**
9. **Describe the ellipsoidal balloons of J.B.M. Meusnier and Henri Giffard. What was their significance in the evolution of human flight? Why did these balloons fall short of achieving sustained flight?**
10. **Explain why progress in airship development lagged for almost a century after David Schwarz introduced the first rigid airship.**
11. **Describe the lighter-than-air craft of Alberto Santos-Dumont and Count Ferdinand von Zeppelin. What two major improvements did Zeppelin's dirigibles bring in man's ability to fly?**
12. **Discuss the achievements of the Graf Zeppelin and the Hindenburg. Why were the giant zeppelins a step forward but not the final answer in man's search for the secret of flight?**

THINGS TO DO

1. Read and report to class on some of the early myths and legends that were expressions of man's desire to fly.
2. Organize a scrapbook showing pictures of early lighter-than-air vehicles. Start with the Montgolfier balloon and include pictures that show how balloon flight finally led to the flights of giant dirigibles.
3. Conduct an experiment to show how the Archimedian principle applies to buoyant flight.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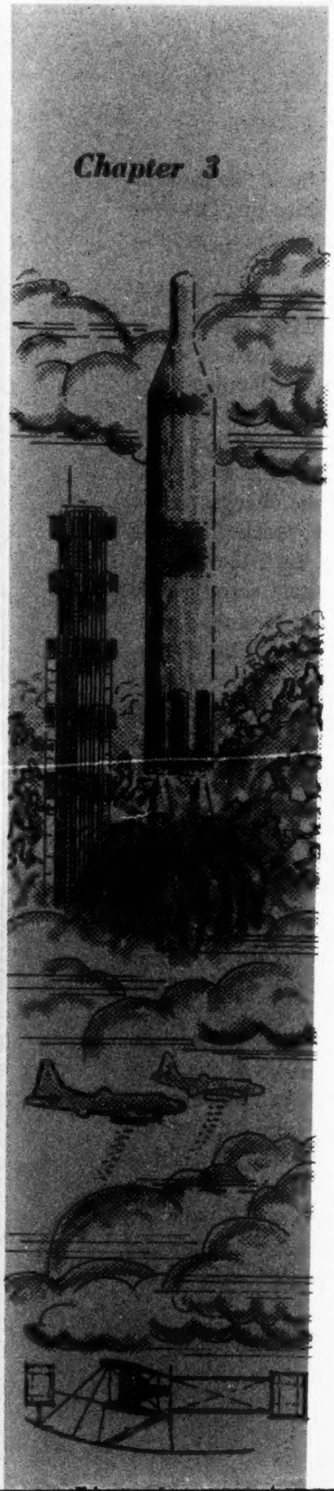
Chapter 3



Winged Flight: A Reality

IN THIS CHAPTER, you will see how the powered aircraft emerged from early experiments with gliders and developed into an effective weapon of war. The chapter first traces the development of gliding and the innovations that led to controlled flight. It then relates how the Wright brothers invented and developed the world's first powered airplane capable of sustained and controlled flight. It discusses subsequent achievements of the Wrights and those of European air enthusiasts in aviation science. The chapter concludes with a discussion of major innovations in the airplane just prior to World War I, the airplane's wartime role, and the effects of war on its basic design. When you have studied this chapter, you should: (1) be able to explain how the principles of flight were explored and applied in glider experiments; (2) know some of the leaders in glider development and explain the importance of their work in the evolution of the airplane; (3) be familiar with the story of Orville and Wilbur Wright and understand the significance of their achievements; (4) be able to trace the development of powered flight and, in addition to the Wright brothers, the contributions of other personalities to progress in aviation; (5) know how the airplane became a weapon of war and the important change brought by war in aircraft design.

MAN UNDERSTOOD the scientific bases of both kinetic and buoyant flight for more than 100 years before the first balloon flight by the Montgolfier brothers. And yet, practically all earlier efforts to fly had been kinetic in nature. A partial explanation lies in the fact that birds themselves do not depend on buoyancy to fly. Man for the most part imitated the birds either by fitting himself with flapping wings or enclosing himself in a machine that would fly under his control. In all of his attempts, however, he invariably faced the problem of moving with enough speed to generate the necessary lift. His own muscles were inadequate, and engines with a proper power/weight ratio were not available.

Heavier-than-air flight made little progress until man realized that wing-flapping was not the answer to his dilemma. For centuries, he searched for the secret of flight in the simple wing movements of birds, but he failed to recognize that birds also fly without flapping their wings. To the naked eye, birds appear to swim through the air with wing movements similar to a man swimming in water. In reality, they achieve propulsion, lift, and braking power by varying the shape and position of their wings. They can make almost infinite changes in the camber (curve), angle of incidence (the angle at which the wing meets the body or "fuselage"), the **dihedral,*** and even the area of their wings. In so doing, they apply many of the same aerodynamic principles as modern aircraft in flying, taking off, and landing. Leonardo da Vinci and other advocates of kinetic flight stood at the threshold of successful winged flight when they imitated the wing movements of birds. They failed in their efforts when they accepted the false premise that birds fly only by means of simple up and down wing movements. Wings extended and motionless held the secret of human flight.

HEAVIER-THAN-AIR FLIGHT

Unlike buoyant flight, heavier-than-air or kinetic flight depends upon the application of power or energy to the resistance of the air. This type of flight applies both Sir Isaac Newton's third law of motion and the Bernoulli principle. Newton's law states that, for every action, there is an equal and opposite reaction. Bernoulli's principle states that, as the speed of the air at a given point increases, the pressure at that point decreases. As air hits the lower surface of the wing, it is deflected downward (action), and the wing is pushed upward (reaction). Also, according to Bernoulli's principle, the curved upper surface of the wing increases the speed of air flowing over it, and a difference in pressure results between the upper and lower surfaces of the wing. This difference in pressure lifts the airplane upward. Kinetic lift, therefore, depends upon the relative motion between the aircraft and the air. It is achieved through the medium of an engine which either drives an aircraft forward through the air or causes a lifting rotor blade to turn. Buoyant lift requires only that the total weight of a vehicle is less than the total weight of the air it displaces.

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* The upward or downward inclination of an airplane's wing or other supporting surface in respect to the horizontal. If the inclination is upward, the dihedral is positive; if downward, negative.

The Beginnings of Practical Aviation

It took exactly 110 years for the practical powered airplane to advance from an idea to reality. The process began with the work of Sir George Cayley in 1799 and ended in 1909 when the Wright brothers demonstrated that powered flight was technically mature. George Cayley was only nine years old in 1783 when the first Montgolfier balloons floated on the wind from France to England. Like other boys of his day, he designed and flew paper balloons. While in his teens, he built a helicopter device equipped with small propellers made of feathers and driven by a whalebone bow. Thoroughly convinced that he could solve the problem of a heavier-than-air flight, he spent his lifetime as an advocate of winged flight. In 1799, he stated the problem of mechanical flight in these words: ". . . to make a surface support a given weight by the application of power to the resistance of the air." In theory, he was taking his first and most important step away from the centuries-old tradition of ornithopters.

To test his theory, he constructed a whirling-arm device to study the effects of air pressure on a square surface at various angles of incidence. He followed his experiment with a model glider that established the basic design of all airplanes (Fig. 16). This simple glider was made of an ordinary diamond-shaped kite mounted on a slender pole about five feet long. On the opposite end, he used a swivel joint to attach a tail assembly that served as the rudder and elevator control. With its forward wing for lift, a tailplane for stability, and a connecting fuselage, this glider had the basic configuration of modern aircraft.

After constructing and flying a number of gliders, one with a wing area of 200 square feet, Cayley wrote his findings in a paper entitled "On Aerial Navigation," which ranks as one of the greatest contributions to winged flight ever made. In it, Cayley set forth basic principles of aerodynamics that guided the development of airplanes for 100 years. Here for the first time, a scientist provided a systematic account of his experiments in winged flight. He included lengthy discussions of the dihedral angle and its role in achieving **lateral stability***. He believed that flight could be stabilized by setting the wings of an airplane at a slight angle to form the profile of a shallow "V." He called attention to

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* The stability of an aircraft against lateral movement, such as sideslipping or yawing.

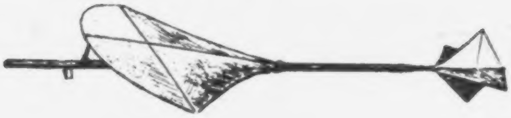

Figure 16. An early glider designed by George Cayley.

the importance of a tail assembly with movable horizontal and vertical surfaces in maintaining **longitudinal stability***. To him also goes credit for the cambered, or curved, wing surface and the prediction that streamlining is necessary to reduce air resistance. Cayley went on to say:

> I feel perfectly confident . . . that we shall soon be able to transport ourselves and families, and their goods and chattels, more securely by air than by water, and with a velocity of from 20 to 100 miles per hour. To produce this effect it is only necessary to have a first mover, which will generate more power in a given time, in proportion to its weight, than the animal system of muscles.

The one barrier to any further success seems to have been that of an efficient engine. Here also, Cayley pioneered as the first man to suggest the internal combustion engine for use in achieving flight.

Aviation took its next important step forward in 1842 when two British scientists, **W. S. Henson** and **John Stringfellow,** applied for a patent on an "Aerial Steam Carriage." The design for this giant monoplane called for a wing span of 150 feet and a tail assembly with horizontal and vertical control surfaces in the shape of a bird's tail. This huge airplane had many of the features found in later monoplanes, including braced cambered wings and a fuselage fitted with a tricycle **undercarriage.**** Henson was the first man to envision a propeller-driven airplane in his proposal for twin six-bladed propellers driven by a 25- or 30-horsepower steam engine. Although this airplane completely failed its test flight because of its heavy engine, it was man's first rational and detailed concept of a powered aircraft.

Henson next collaborated with his good friend John Stringfellow in building a monoplane with a 10-foot wing span, driven by a small steam engine. When this model failed to sustain itself in flight for any distance, Henson gave up in despair and took no further part in aeronautics. Stringfellow built another smaller model with two four-bladed pusher propellers, driven also by a steam engine. This model achieved only a part-glide, part-powered flight and crashed shortly after launching. These men, to their own chagrin, proved that steam engines were not the answer to the problem of power.

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* The stability of an aircraft against periodic pitching, climbing, and diving motions.
** A three-wheeled landing gear.

In 1866, **F. H. Wenham** made an important contribution to mechanical flight when he read a technical paper to the Aeronautical Society of Great Britain. He suggested a multi-wing design to improve the lifting surface of the airplane. This idea eventually led to the development of the biplane. He also proposed the use of a slight camber along the front surface of the wings to provide more lift. He is also credited with building the first wind tunnel to test wing shapes.

Other developments in aviation came in 1871 when a young Frenchman, **Alphonse Penaud,** built and flew a model airplane with a pusher propeller powered by a twisted rubber "motor." This plane was unique because it possessed both inherent lateral and longitudinal stability. Dihedral of the main wing reinforced by upturned wing tips provided lateral stability, and a tail surface behind the main wing set at a smaller angle of incidence than the main wing provided longitudinal stability. (George Cayley had proposed the same features in the eighteenth century.) Penaud made his greatest contribution to winged flight in 1876 when he designed an amphibious monoplane with a **retractable landing gear,*** a glass cockpit canopy, and a single stick to control rudders and elevators. Although Penaud and his contemporaries never achieved powered flight, their experiments show how far man had advanced in the mid-nineteenth century toward making such flight a reality. The airplane in its modern **configuration** design was slowly taking shape.

The Fixed-Wing Glider

Except for the studies and experiments of George Cayley and his followers during the first half of the nineteenth century, there were few other significant developments in aviation. Man had created model gliders that flew, and he had attempted to add engine power to his gliders. He still had not found a way to transport himself on wings through the air. Most of the would-be fliers were firmly convinced that they could achieve winged flight only if they had suitable engines. The result was volumes of writings on the theory of flight and seemingly endless accounts of experiments with models.

Further progress in aviation came during the latter half of the nineteenth century with the pioneering efforts of a German engineer-scien-

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* Landing gear capable of being drawn into, or up against, the aircraft.

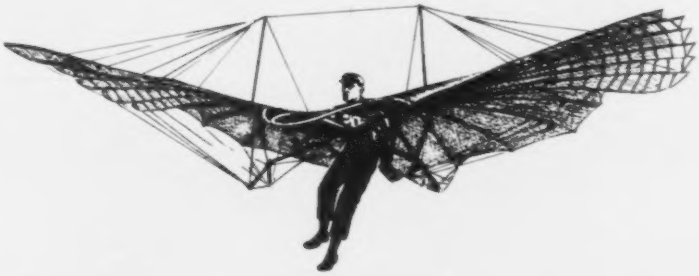

Figure 17. Lilienthal's gliders had cambered wings and fixed tail units with vertical and horizontal surfaces.

tist, **Otto Lilienthal,** who became known as "the father of the glider." While his contemporaries continued to practice with flying models, Lilienthal became weary with theorizing and decided that practical experience must be the next step in learning to fly. He commented to his brother Gustav: "To conceive of a flying machine is nothing; to construct one is something, but to make a trial of it is everything." He had spent almost 18 years studying bird flight, testing airfoils of all shapes, and working out formulas for proper wing design. In 1891, he built his first **fixed-wing monoplane*** and became the first man to fly in a heavier-than-air craft, even though he had no engine. Between the years 1891 and 1896, he made 2,000 successful flights with a total flying time of about five hours.

Lilienthal's gliders had cambered wings and fixed tail units with both vertical and horizontal surfaces (Fig. 17). He launched his first glider from a springboard but later constructed a cone-shaped hill for takeoffs into the wind regardless of wind direction. He achieved flight by running downhill until he reached flying speed. In flight, he placed his forearms in armlets attached to the center section of the wing framework. His head and shoulders projected above the wings and his body and legs below. He achieved control and stability by shifting the **center of gravity**** with movements of his body.

In 1896, he turned to powered flight in a glider with flapping wing tips operated by a small carbon dioxide gas motor. His design for this glider included a revised pilot control system for elevating the surfaces of the tailplane in coordination with his body movements. A headband joined the pilot to the tailplane. When he lowered his chin, the plane rose, and, when he lifted his chin, it descended. Before he completed this new machine, he took off in a gusty wind on one of his older gliders. At 50 feet, the glider stalled and crashed to earth. Lilienthal suffered a broken back and died the next day.

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* An airplane with a single wing attached to the fuselage. The wing may be fixed in place or adjustable, as distinguished from an airplane with rotating wings like a helicopter.

** The point at which the combined force of all the weight forces in a body, as an airplane, are concentrated for any position of the body.

Lilienthal is remembered as one of the great air pioneers who flew consistently and successfully in a heavier-than-air craft. Printed descriptions and photographs of this man in flight were made available to people all over the world. These photographs and his technical writings provided convincing proof to other advocates of winged flight that the air would support fixed-wing flight, with or without engine power. Although Lilienthal was an avid student of bird flight, he was the first man to conceive of human flight on fixed, motionless wings rather than on flapping wings like birds. He demonstrated by personal example that it was both possible and necessary for man to get into the air and fly before he would be able to design and control a practical airplane. His work directly influenced the Wright brothers, who praised his pioneering efforts even after they had to modify some of his findings.

While Lilienthal flew fixed-wing gliders in Europe, **John J. Montgomery** designed and flew man-carrying gliders in the United States. On his parents' farm near San Diego, California, in 1884, Montgomery secretly built a glider with wings shaped like those of a sea gull. To avoid the ridicule of neighbors, he and his brother launched the glider during the early morning hours from a gently sloping hill. Montgomery faced the wing surface of his glider into a 12 mile-an-hour breeze, while his brother ran downhill with a pull rope. The glider with Montgomery's 130 pounds soared to a height of 600 feet before easing to the ground.

Montgomery based the design of his gliders on flapping-wing flight proposed by George Cayley, but he introduced a new idea when he used flaps on the wing tips. The flaps were held in place by light springs that allowed the flaps to push down during wind gusts and restore the **equilibrium** (balance) of the glider. From 1886 through 1892, Montgomery demonstrated through thousands of experiments that cambered, fixed wings were the most important elements of successful flight.

In 1905, he unveiled his most recent glider before a crowd of 15,000 people at Santa Clara, California. This glider had dihedral cambered wings placed in tandem, one pair behind the other. The pilot was Daniel Maloney, a man known for his parachute jumps from hot-air balloons. With the glider attached to a balloon, Maloney rose to 4,000 feet and cut himself loose from the balloon for a controlled glide back to earth. Twenty minutes and eight miles later, Maloney landed at a preselected spot about three-fourths of a mile from his starting point. During his flight, he guided the craft in sharp dives, spirals, and turns and reached speeds of almost 70 miles per hour.

The next forward step in the evolution of the airplane came in the late nineteenth and early twentieth centuries with the experiments of an eminent American civil engineer, **Octave Chanute.** When Otto Lilienthal died in 1896, Chanute had already won recognition in bridge building with his design of the first bridge to span the Missouri River. He became interested in aeronautics at the age of 43 when he began collecting information on the history of aviation. He was captivated by Lilienthal's achievements in gliding and, like Lilienthal, publicly urged would-be flyers to build full-size gliders and experiment with them in actual flight.

At the age of 60, Chanute used his knowledge of bridge rigging to build a number of man-carrying gliders based generally on Lilienthal's design. Chanute was too old to fly, but he supervised hundreds of flights by an assistant on the shores of Lake Michigan near Chicago. Early in his experiments, Chanute decided that single-wing gliders could not be controlled satisfactorily, even with the pilot's body movements. His aim was to develop a glider with built-in or inherent stability that would make body movements unnecessary. His first change in the Lilienthal design was a multi-winged glider with wings that moved backward and forward to adjust to sudden air pressure. This ingenious device, by Chanute's own admission, was not practical. His second glider began as a triplane but soon became the famous Chanute biplane, a design used in powered aircraft for many years following Chanute's flights.

This biplane glider had cambered wings braced with a so-called **Pratt truss*** derived from Chanute's experience in bridge building (Fig. 18). Chanute achieved added stability by suspending the pilot well below the wings. This allowed further adjustment in the center of gravity. The glider had a fixed tail with spring attachments to allow up and down movements that acted as gust dampers. It made hundreds of successful flights, reaching airspeeds of more than 50 miles per hour and heights over 350 feet.

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* A system of crossing diagonal braces of wire or rods between the wings of a biplane.

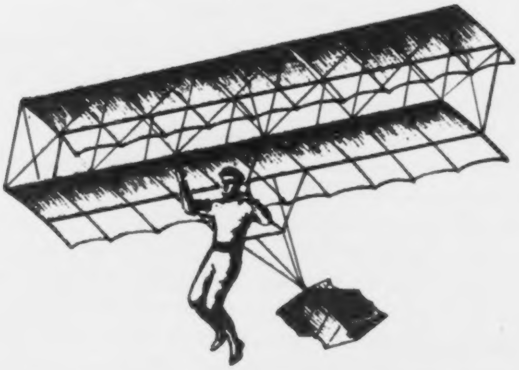

Figure 18. Octave Chanute's biplane glider with bridge-truss wing rigging.

Chanute achieved an amazing degree of control and structural stability in his gliders. Although he continued the Lilienthal technique of swinging body movements, he improved on Lilienthal's method by having the pilot push his whole body backwards and forward with his arms on rail supports. Chanute's major technical contribution to the advancement of aviation was his biplane with its bridge-truss method of wing rigging. In addition to his technical achievements, he exercised a powerful influence on aviation through his advice and encouragement to other air pioneers.

In 1900, at the age of 68, he became the most trusted confidant of the Wright brothers, offering advice and assistance in their efforts. He not only offered financial assistance, which was declined, but also wrote volumes of technical correspondence for their use and even made personal visits during their experiments at Kitty Hawk, North Carolina. In 1903, he presented illustrated lectures on his and the Wright brothers' achievements to the Aero Club in Paris, France. As a kind of ambassador for aviation, he had the extraordinary effect of initiating the aviation movement in Europe. He was a dedicated "middle man" in the evolution of flying, always confident that powered flight was inevitable.

Thus, by the end of the nineteenth century, man had expanded his knowledge of aerodynamics to the point that winged human flight had become a reality. He had learned and applied the fundamentals of kinetic lift in the flights of fixed-wing gliders. His next problem was to combine a reliable source of controllable power with an efficient steering system.

Powered Flight

Ever since George Cayley concluded that power was necessary for winged aircraft to overcome the resistance of air, the pioneers of winged flight had attempted to develop engines with an acceptable **power/weight ratio.*** Some had experimented with "motors" of twisted rubber; others had tried steam-, oil-, electric-, and gasoline-driven engines of various sizes and weights, to no avail. One of the most important technological developments in the latter part of the nineteenth century was the arrival of the gasoline-driven automobile. As public demand increased for the so-called "horseless carriages," engine designers sought constantly for lighter and more powerful motors. Gasoline engines not only made the automobile more powerful, but also created a need for professional drivers, engineers, and mechanics, many of whom later became aviation enthusiasts. As the automobile improved, so did its engine. And, as the engine increased in power, it became a potential power plant for the airplane.

Toward the end of the nineteenth century, **Clement Ader,** a French electrical engineer, and Hiram Maxim, the inventor of the machine gun, almost achieved powered flight with steam engines. Ader built an **unbraced monoplane**** with tapered wings, a closed cockpit, and wheeled undercarriage. He equipped it with a lightweight steam engine, and, according to nine witnesses, managed a short hop in the air of 160 feet. The wings of this plane took the shape of bat wings, bent at the tips to deepen their camber. Flexible propellers changed their shape at different speeds. After crashing his second plane, Ader built a third machine equipped this time with two tractor propellers driven by two 20-horsepower steam engines. This plane overturned and crashed in a heavy wind, and Ader lost further interest in aviation. He failed primarily because he was never able to develop an effective wing design, stability, or control in his airplanes. He could not extend his short powered hops to sustained and controlled flying.

In the early 1890s, **Hiram Maxim** built a railroad track one-half mile long, and, on it, he mounted a giant biplane with dihedral wings extending 104 feet from tip to tip. This machine had two propellers 18 feet in diameter, driven by two steam engines that developed an astounding 360 horsepower. Including water, fuel, and three crew members, the plane weighed 8,000 pounds. When he designed this monstrosity, Maxim was concerned only with creating a machine that would lift itself from the ground and not one that would fly. He anchored it to the ground with guard rails that permitted it to rise only a few inches above the ground. On the main test, Maxim drove the machine at top speed until it lifted from the tracks and broke the guard rails. He was about to lose control when he shut off the steam and brought his slightly damaged giant to a stop (Fig. 19). He brusquely announced his conclusion: "Propulsion and lifting are solved problems; the rest is a matter of time." He felt that he had discovered the secret of flight and devoted no further effort to his project. For all his expense and effort, he too had made no provision for sustained and controlled flying.

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* An engine sufficiently light but powerful enough to drive an airplane.
** A monoplane that does not have external braces on its wings.

Many people believe that aviation had its real beginning in America with the work of **Samuel P. Langley,** a director of the Smithsonian Institution. Well in his fifties when he became interested in aviation, Langley contended that he could design an airplane capable of balancing itself in the air without the aid of a pilot. He began by testing the behavior of small models on a whirling arm and in flight, driven by twisted rubber bands. He later studied a small steam engine designed 20 years earlier by **John Stringfellow** and decided that he could build a

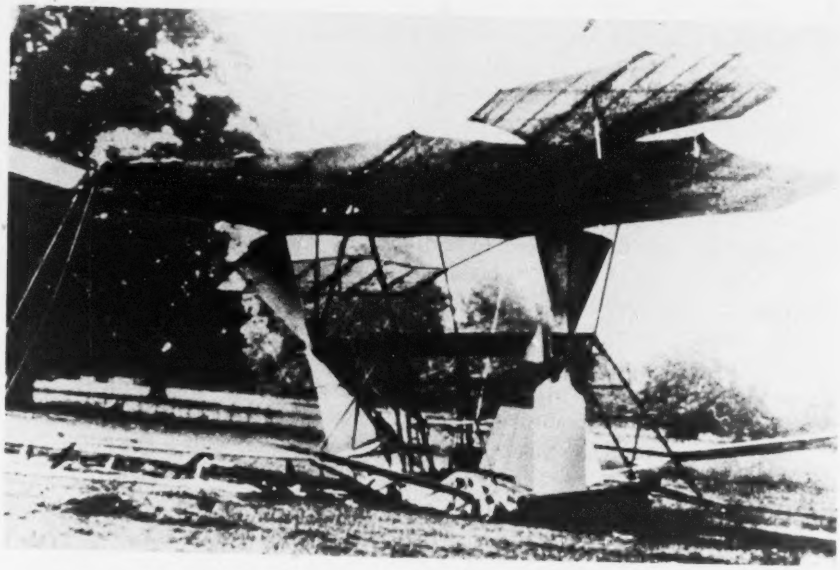

Figure 19. Hiram Maxim's biplane as it appeared after a takeoff of one foot in 1894.

better one. For five years, he worked on four different models with steel frames that would not fly. Finally, after five years of failure, he built a steam-driven tandem monoplane, with two pairs of wings placed one behind the other and set in the fuselage at a slight **dihedral angle** for lateral stability. In the presence of Alexander Graham Bell and other friends in 1896, Langley launched his machine from a houseboat on the Potomac River. The plane rose to an altitude of 100 feet and flew three-quarters of a mile at a speed of 30 miles per hour. It landed without damage only after it had run out of fuel.

Following the successful flight of this model, the US Government granted Langley $50,000 to build a power-driven airplane capable of carrying a man. Langley, meanwhile, had decided that a gasoline engine offered more promise for powered flight than a steam engine. Several manufacturers told Langley that they could not fill his order for a 12-horsepower engine weighing 100 pounds. He then assigned the project to an assistant, Charles Manly, who selected a gasoline engine with its cylinders arranged in a circle around a crankshaft. After reworking this engine, Manly hoped that it would produce as much as 20 horsepower. Actually, the five cylinders of this little power plant produced almost 53 horsepower, a record that went unbroken for about 14 years. The motor weighed less than 150 pounds; therefore, the ratio of pounds to horsepower was less than 3 to 1.

Langley's Aerodrome marks the first time that the Government had offered a grant for a man-carrying winged aircraft (Fig. 20). It measured 52 feet long and 48 feet from wingtip to wingtip and, with the pilot, weighed 750 pounds. The engine provided power for two propellers mounted between the tandem wings. Both Langley and Manly were confident that they were about to achieve the first sustained, controlled heavier-than-air flight in history.

Langley had launched his earlier models by **catapult*** from a houseboat on the Potomac River, and he chose the same method to launch his Aerodrome. Before a gathering of US Government representatives and newspaper reporters in October 1903, Langley and his assistants made final preparations for the test. The catapult was set, and Manly climbed aboard, started the engine, and gave it full throttle. The catapult released, and the plane shot forward. And then, with a grinding and roaring noise, it jerked to a halt and slipped into the Potomac. A pin on the launching car had failed to release. Manly escaped with only a dunking, but the airplane took two months for repairs. On 8

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* A device for pushing an airplane, missile, or the like into the air from a ramp, rack, or truck, usually at high initial speed.

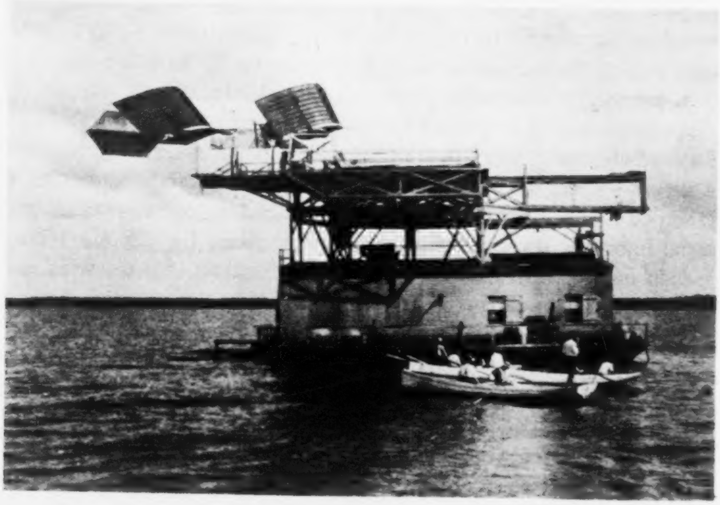

Figure 20. Samuel P. Langley's Aerodrome was a gasoline-driven tandem monoplane.

December 1903, the press and Government representatives again gathered on the banks of the Potomac. Manly took his position. The engine roared, and the craft catapulted into the air, zoomed unexpectedly straight up, held its altitude a moment, and then fell back into the Potomac. The tailplane had collapsed at the time of launching. Again Manly was fished uninjured from the water.

Langley was subjected to heavy criticism at the hands of the newspapers and the public. It was indeed a disappointing experience for the 70-year old scientist who died shortly thereafter. Only nine days after Langley's failure on the Potomac, Orville and Wilbur Wright made their historic flights.

The Wright Brothers

On a cold, blustery morning just south of Kitty Hawk, North Carolina, in December 1903, man fulfilled his centuries-old dream. The scene was the lonely sand dunes known as the Kill Devil hills. A 20-mile an hour wind whipped clouds of sand across the dunes as a small group of seven men approached a dilapidated wooden structure. From this crude "hangar," they towed a frail biplane to a launching device consisting of a wooden rail about eight inches high and a small trolley car with a crossbeam fixed to it. One of the men took a prone position as pilot, face down, on the lower wing of the plane, while another man stood at the wingtip to steady the plane against the wind. The pilot took two or three minutes to bring the engine to its full power and then released a restraining wire. Moving slowly at first, the trolley picked up speed as it reached the end of the track. The pilot raised the **forward elevator,*** and the machine rose into the air. For 12 seconds, it surged against the wind at a forward speed of seven miles per hour. It settled to the ground 120 feet from its launching point. Without personal injury or severe damage to their machine, **Orville** and **Wilbur Wright** had just flown man's first powered aircraft into the wind and brought it back to earth.

Some of the world's most talented engineers had experimented with flight and had failed. Two bicycle mechanics had discovered the secret of flight, largely through their own efforts. Although they had been fascinated with flying models since boyhood, they had become actively interested in flying when they heard of Otto Lilienthal's tragic death. After studying the experiments and writings of Lilienthal, Chanute, and Langley, they decided that experience in gliding was a necessary first step in solving the problem of human flight. With their first glider, a five-foot model of Chanute's biplane, they prevented nose dives with ropes that controlled the horizontal and vertical tail surfaces. But, like their predecessors, they found it impossible to maintain lateral stability. One wing always seemed to be higher or lower than the other wing. Now they understood why Lilienthal dangled below his glider and why Chanute moved his glider wings backward and forward. Neither method was a satisfactory approach to sustained flight.

Like Lilienthal and others before them, the Wright brothers studied the flight of birds, but they saw more than simple up and down flapping motions. Orville observed buzzards through field glasses and found that they balanced themselves in the wind by dropping one wing and lifting the other. In light winds, only tips of their wings were involved—the tip of one feather went up while its diagonal opposite on the other wing went down. Here was the solution to the problem of lateral balance. A pilot must have the ability during flight to vary the lift of either wing tip. Both brothers spent months searching for an appropriate device. Wilbur discovered it one day quite by accident while twisting the ends of a cardboard box. If the box could be twisted without damaging its strength, why could he not also twist the diagonal tips

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* Control surface located in front of the wings.

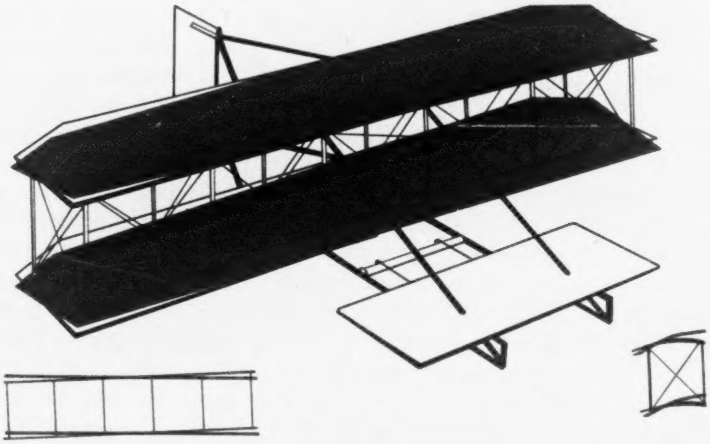

Figure 21. A sketch of the Wright brothers' first glider with "wing warp." The shaded areas show how wing warping or twisting was used to control the craft. Later airplanes used ailerons to perform this operation.

of glider wings with a wire shoulder harness as he lay prone on the wing?

With this discovery, the Wrights held the key to three areas of control. The pilot could manipulate an elevator with his right hand to control up and down or longitudinal movement, operate the rudder with his left hand to swing right or left, and maintain lateral balance by swinging his shoulders to twist the wing tips. This so-called helicoidal twist gave the wings a shape similar to that of a propeller or a strip of twisted crepe paper. A shallow twist maintained the horizontal balance of the wings and permitted the pilot to **bank*** his glider at will. If he wanted to lift the right wing, he worked the controls to twist the leading edge of the right wing upwards. At the same time, the leading edge of the left wing would twist downward, and the left wing would dip. The Wrights referred to this significant innovation in flying as **"wing warping"** (Fig. 21). They tested this technique in their first glider, flying it as a kite and operating the wing-warping controls by hand. The test was an unqualified success. They had discovered the secret of lateral balance and were now ready to test a man-carrying glider.

In September 1900, they built their first manned glider on the basis of Lilienthal's tables of air pressures. This glider had fixed biplane wings with a 17-foot span, warping control, a movable forward elevator or rudder, and a prone pilot position to reduce resistance and make landing safer. Although the glider was far from satisfactory, it confirmed several basic ideas that were to be incorporated in other gliders. The Wrights learned, for example, that, by placing the horizontal surface of the elevator in front, they could prevent nose dives. They also found that dihedral wings did not provide automatic stability in gusty conditions. They abandoned the **dihedral** angle and adopted the idea of a slight downward droop. Their second glider had a wing span of 22 feet, an anhedral droop of 4 inches, and warping wires operated with a hip harness. Although Wilbur made glides up to 389 feet, the glider slideslipped and crashed when he warped the wings in banking. Completely dismayed at this new development, Wilbur began to doubt the accuracy of Lilienthal's calculations. "Having set out with absolute faith in the existing scientific," he wrote, "we were driven to doubt one thing after another till finally, after two years of experiment, we cast it all aside, and decided to rely entirely upon our own investigations."

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* To incline an aircraft laterally, usually when making a turn, to prevent skidding.

After almost a year of testing models and wings in homemade **wind tunnels,*** the Wrights in 1902 built a third glider based on their own observations and measurements. This glider had a wing span of 32 feet and a width of 5 feet, giving it the appearance of a sea gull in flight. It was a much larger craft and one that only a skillful pilot could control. In addition to a front elevator and cambered wings with an anhedral droop, the Wrights placed two fixed vertical rudders in the rear, hoping to correct a tendency to spin and yaw when they warped the wings. This only increased the violent twisting of the glider. Their next move was to change the fixed twin rudders into a single movable rudder. Now, at the moment of warping, the pilot could swing the rudder to correct an exaggerated tilt when he made a turn and then reverse the swing to redirect his flight. With this combined warp and rudder operation, the Wrights solved the basic problems of balance and control in glider flight. They had unknowingly designed the forerunner of the modern aileron, a control that enables a pilot to bank his aircraft to the left or right.

Experience with their third glider proved to the Wright brothers that their machines should be made inherently unstable. This feature allowed a high degree of sensitivity and response to the control of a skilled pilot. It meant that the pilot had to view himself as a living and working part of his aircraft and not merely as a chauffeur whose only concern was to drive his plane through the air as he would an automobile. They deliberately built an unstable but highly maneuverable machine that would not right itself in the air without the pilot's direction.

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* This was probably the first time that wind tunnels were used to test aircraft models for data to be used in the design of larger vehicles.

Upon their return to their bicycle business in Dayton, Ohio, in October 1902, Wilbur and Orville Wright had every reason for excitement. They had, for all practical purposes, solved the major problems of controlled flight. They still faced two formidable obstacles to powered flight—the problem of a light but powerful engine and the development of propellers. When they discovered that automobile engines were too heavy, these remarkable men designed and built a four-cylinder water-cooled engine that weighed almost 200 pounds and produced 12 horsepower. This provided a power/weight ratio that would be sufficient to lift their new *Flyer* into the air. Their most perplexing problem was that of developing suitable propellers. At first, they planned to adapt formulas for the design of boat propellers to their requirements for air propellers. Again, they found themselves on a frontier of little or no knowledge. From their own research, they designed and built far more efficient propellers than those built either by Maxim or Langley.

For their first powered flight, the Wright brothers built a much larger biplane than their third glider (Fig. 22). Their *Flyer* had a wing span of more than 40 feet, landing skids, a biplane elevator in front, and a rear double rudder linked by control cables to the warp cradle. Bicycle sprockets and chains connected their gasoline engine to two wooden pushed propellers. To counteract the twisting force **(torque)** generated by their rotation, the propellers revolved in opposite directions. The wings were simple wooden frames covered with cotton fabric and held in place one above the other with wooden struts braced with piano wire.

By 12 December 1903, the Wrights were ready for the first test of their powered glider. With the toss of a coin, Wilbur won the privilege of making the first flight. Only a few people were on hand for this demonstration, and they were disappointed. As Wilbur piloted the machine forward, he raised the front elevator too high, and the *Flyer* fell backward into the sand. Three days later on 17 December 1903, Orville rose into the morning air for a flight lasting 12 seconds. In Orville's words, this flight was "the first in the history of the world in which a machine carrying a man had raised itself by its own power into the air in full flight, had sailed forward without reduction of

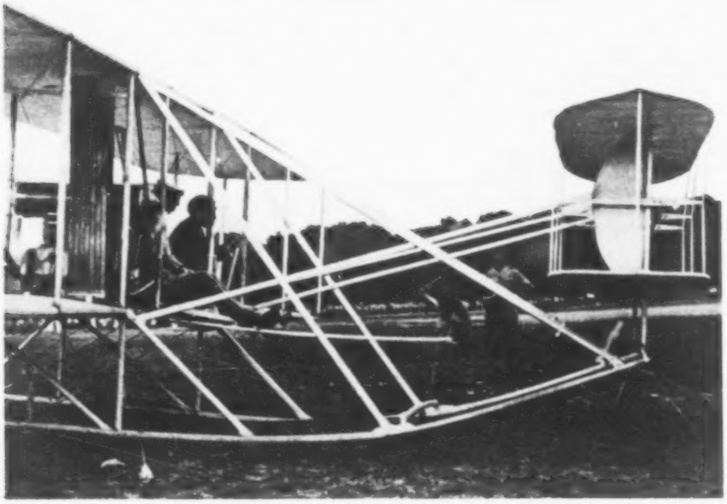

Figure 22. The Wright *Flyer* was an inherently unstable aircraft with a biplane elevator in front and a rear double rudder.

speed, and had finally landed at a point as high as that from which it started."

With Wilbur and Orville alternating as pilot, the brothers made three additional flights that morning. The longest flight covered 852 feet in 59 seconds, but, through the air, the distance was over half a mile. Determined now to produce a more practical plane, they designed two other Flyers. The design of *Flyer No. 2* in 1904 was much the same as No. 1 except for a reduced camber of the wings, a new engine of 20 horsepower, and an improved gear linkage between the engine and the propellers. They introduced for the first time a device to assist them in takeoffs. This device consisted of a weight suspended by a rope inside a tall derrick. The other end of the rope extended from the top of the derrick down a launching track where it was attached to a small trolley car on which the airplane rested. When the weight was released, the trolley moved rapidly down the track at a sufficient speed to assist in takeoff. With only a few exceptions, aircraft designed by the Wright brothers used this device until 1910.

Most of the flights made during 1904 covered short distances at low altitudes. During this period, the Wrights concentrated on flight control, care of their engine, and use of the takeoff device. In a total of

105 flights, they experienced two major achievements and one perplexing problem. Wilbur made the first circular flight in September and, two months later, made the first flight of more than five minutes when he made four circles covering a distance of almost two and three-fourths miles. They did not solve a major problem of control—a tendency to stall in tight turns—until they built *Flyer No. 3* in June 1905. The Wright *Flyer No. 3* became the world's first practical powered airplane. Although it had much the same configuration as the other Flyers, it featured important differences. For improved longitudinal control, it had a larger biplane elevator placed farther forward and a double rear rudder farther back. It had a wing span of 40 feet 6 inches, a slightly increased camber, and improved propellers. It stood higher on its skids and presented a much more robust appearance.

Like all Wright biplanes, it was an inherently unstable aircraft that required the pilot's attention at all times. The Wrights solved the remaining problem of control in tight turns by putting the nose down and increasing speed. While searching for the solution to this problem, however, they made other important changes in their flight control system. For one thing, they separated the warp and rudder controls. This permitted any degree of combined or independent warp or rudder movement. With this change, the pilot could use the warp controls to establish lateral balance in wind gusts without turning the aircraft with the rear rudder. This contributed still further to the mastery of mechanical flying. The final step came in 1908 when the brothers modified *Flyer No. 3* to allow the pilot to sit upright. For all practical purposes, they had gained mastery of the air and had introduced the age of the flying machine.

Although Wilbur and Orville had flown constantly from 1903 to 1905, the press and the public looked upon their achievements as the eccentric efforts of two young upstarts. By 1905, however, their flights had attracted worldwide attention. The brothers became increasingly concerned that unscrupulous people would steal their design. After much delay, they received a patent on their aircraft and offered their invention to the governments of the United States and Great Britain. Negotiations at first proved fruitless because the Wrights wanted a guarantee of purchase before they gave public demonstration. They crated one of their machines and took it to France in 1907. No one would agree to pay their price of $250,000 without prior demonstration. The brothers returned home and left their machine in a crate at Le Havre. For two and one-half years, from 16 October 1905 to 6

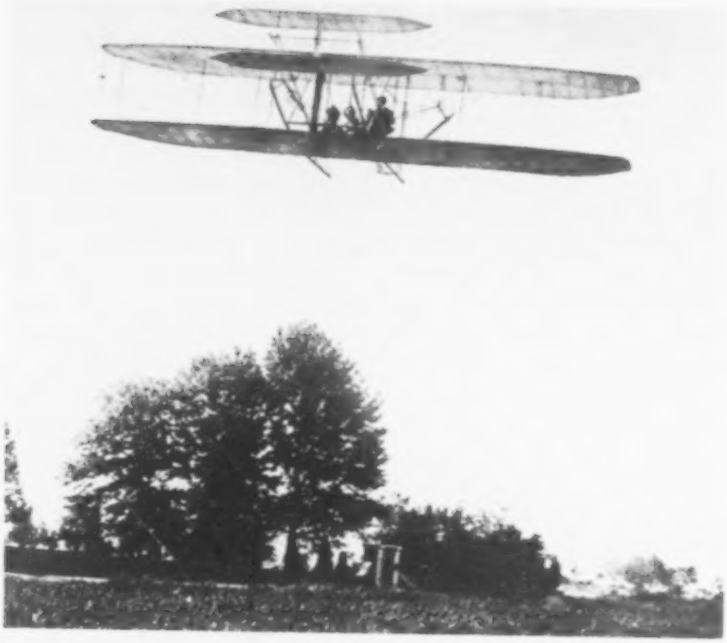

Figure 23. The Wright biplane in one of a series of test flights for the US Army at Fort Myer in 1908.

May 1908, they built no planes, made no flights, and allowed no one to see their machines.

Finally, in the spring of 1907, President Theodore Roosevelt directed the Secretary of War to study the possibilities of the Wright plane for military use. With Wilbur's help, the US Army drafted its first public request for bids on an aircraft. The specifications called for an aircraft that could carry a pilot, a passenger, and fuel for a 125-mile trip; fly at least 36 miles per hour under perfect control; and take off and land in any likely war zone without damage. During the same period, a French syndicate bought the Wright brothers' patent rights for $100,000. Wilbur immediately sailed for France where he demonstrated the performance of the Wright machine before European government officials and businessmen.

In the meantime, Orville built a new airplane for Army test flights at Fort Myer, Virginia (Fig. 23). He arrived at Fort Myer in late August 1908 and, on 3 September, made a 71-second flight before a crowd of spectators. He gave a brilliant performance in his new two-seater biplane, demonstrating almost effortless control in banks, turns, circles, and even figure eights (Fig. 24). On 8 September, tragedy struck during the last day of the test series when he made a flight with a passenger, Lt Thomas Selfridge, a Signal Corps balloon pilot who had helped Glenn Curtiss and Alexander Bell with flight experiments.

After four minutes in the air, Orville heard a warning noise behind him. The machine shuddered violently and swerved sharply to the right. Orville cut the engine and then found that the rear vertical rudder would not respond to the controls. Using the greatest possible wing-warp, he managed to turn the craft away from a cluster of trees and back toward the parade ground. A cracked propeller led to a whole series of mechanical failures, and the plane suddenly plummeted to the ground from an altitude of 75 feet. Orville was seriously injured, and Lt Selfridge died after suffering a fractured skull. He was the first pilot to die in the crash of a powered plane.

Orville recovered from his injuries by mid-July 1909 and returned to Fort Myer with a new plane to complete the tests. His new plane more than satisfied Army requirements. The US Government formally purchased the Wrights' machine for $30,000 and, with one plane and two pilots, established the **Signal Corps Aeronautical Division.** This

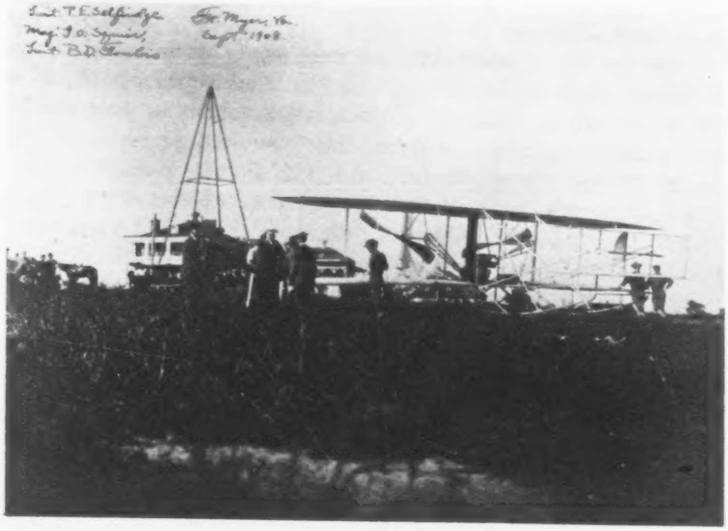

Figure 24. The Wright biplane poised on its catapult at Fort Myer just prior to takeoff.

might be considered as the beginning of today's United States Air Force.

Powered Flight in Europe

The prospects of achieving powered flight in a controlled airplane were almost nonexistent in Europe during the early 1900s. Despite the miraculous flights of the Wright brothers, European interest focused primarily on balloons and dirigibles. Count Zeppelin, Santos-Dumont, and others had captured the public imagination with the controlled flights of their buoyant airships. Only a very small group of pioneers in heavier-than-air flight continued to test gliders based on Otto Lilienthal's experiments. Chief among these was French army Captain **Ferdinand Ferber,** who had built gliders without much success since 1899. He first became aware of the Wright brothers' work in 1902 through correspondence with Octave Chanute. On the basis of information supplied by Chanute, Ferber built imitations of the Wright gliders but failed in his attempts to get them in the air. This led him to conclude mistakenly that the Wrights were making little or no progress. Only after Chanute lectured in person before the French Aero Club in April 1903 did the European aviation movement get under way. Its major proponents were such men as Ferber, **Robert Esnault-Pelterie, Ernest Archdeacon, Louis Bleriot, Gabriel Voisin,** and **Alberto Santos-Dumont.**

In his lectures, Chanute provided these men a blueprint for success in heavier-than-air flight. He explained in detail the technical basis of the Wright brothers' concept of deliberate instability in their gliders, their method of lateral control, and their combined wing-warping and rudder control system. At first, men like Ferber, Esnault-Pelterie, Archdeacon, and Voisin attempted to make exact copies of the Wright gliders. They failed miserably either through skepticism or a misunderstanding of the control system used by the Wrights. Although their failures delayed the growth of European aviation, they also led to significant new developments in the evolution of the airplane.

Almost without exception, the European pioneers rejected the concept of instability and concerned themselves with built-in stability. Ferber, for example, built several copies of the Wright machines but included no wing warping and very little elevator control. He finally added a stabilizing horizontal tailplane to the front elevator, dihedral to the wings, and ineffective rudders on the wing tips. He established inherent stability as a basic European biplane design—front elevator, wings, and an outrigger with a horizontal fixed tailplane. Esnault-Pel-

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terie rejected wing warping as too dangerous and invented the forerunner of the modern aileron system. Pelterie's system consisted of two independent horizontal rudders or elevators attached to the front of the wings and connected to a small steering device. Although his glider failed to fly, all other ailerons derive from this initial effort by Pelterie.

The most significant development in European aviation came in 1905 with the design of two float gliders by Gabriel Voisin in cooperation with Archdeacon and Louis Bleriot. Voisin's gliders retained the biplane and forward elevator design of the Wright brothers but included side curtains on the wings and tail unit to form a kind of **box-kite configuration.*** Here again, the Europeans were applying the concept of built-in stability in their efforts to build a flying machine. They viewed the airplane as a kind of flying automobile to be steered through the air. They rejected the idea of the pilot as a vital part of the flying process. Although the Voisin gliders enjoyed only limited success, they established basic European biplane design.

No other important developments occurred in the European aviation movement until 1906. **Leon Levavasseur** perfected two gasoline-powered Antoinette engines (named after Antoinette Gastambide, the daughter of a close friend), one of 24 horsepower and the other of 50 horsepower. These engines became the chief source of power for European aviation. Toward the end of the year, Alberto Santos-Dumont, the man who had floated over Paris with his gas-filled airships, made the first officially recognized powered flight in a winged aircraft over Europe. His 14–Bis was a huge biplane with box-kite wings set at a deep dihedral angle. Instead of including a rear tail unit for longitudinal stability, Santos-Dumont made the front elevator outrigger into a long covered fuselage. On the front end of this fuselage, he included a smaller box-kite arrangement to serve as a combined elevator and rudder (Fig. 25). The wings and fuselage were made of pine and bamboo covered with fabric. The plane rested on two main wheels with rubber shock absorbers and a skid under the forward tail unit. It was a basic Wright configuration of biplane with wings and forward elevator modified by a box-kite design. The plane depended for thrust on a pusher propeller driven by a 50-horsepower Antoinette engine. The pilot stood in a wicker basket in front of the engine. After testing this plane suspended under one of his dirigibles, Santos-Dumont made one flight of 197 feet and another of 722 feet. His only contribution to aviation

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* Having the appearance of a box-kite.

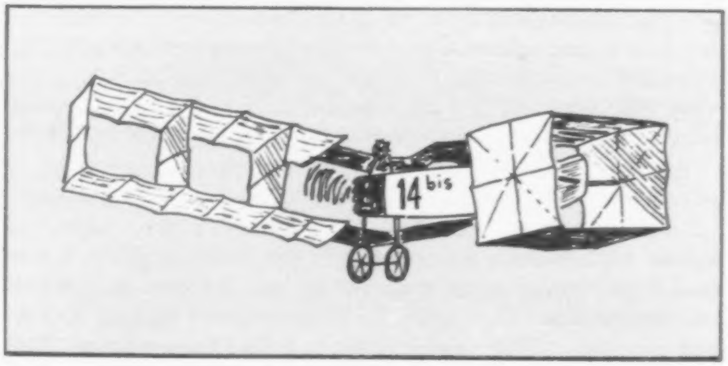

Figure 25. Santos-Dumont's 14-Bis was a biplane with dihedral box-kite wings, a covered fuselage, and a smaller box-kite arrangement that served as elevator and rudder.

was to draw attention to dihedral wings at a time when European interest in lateral control did not exist.

Meanwhile, such men as Voisin, Bleriot, Henri Farman, and others continued their efforts to design a powered biplane with built-in stability. Little was accomplished in solving such basic problems as lateral control and propeller design. One of the most significant developments in European aircraft design came in 1907 when Louis Bleriot decided to experiment with powered monoplanes. His third monoplane was a direct forerunner of the modern monoplane. It had an enclosed fuselage, large forward wings, and a tail unit consisting of a rudder, elevator, and ailerons. Bleriot made five short flights in this plane before it crashed. Early in 1908, Henri Farman made a flight of about one mile in a Voisin biplane with a box-kite tail and side curtains between the wings. Other short flights by Bleriot in France and A. V. Roe in England were the only significant European accomplishments in aviation by the time Wilbur Wright appeared in Paris with his 1905 model Flyer.

When Wilbur appeared at a small race track near LeMans, France, on 8 August 1908, he faced a skeptical audience of European aviators and would-be aviators. They had heard and read first-hand accounts of the Wright brothers' achievements in America, but no one believed them. In flight after flight, Wilbur not only astounded, but dismayed, his onlookers with graceful banks, turns, and circles. Between August and December, he made over 100 flights, carrying about 60 passengers and remaining airborne over 25 hours. By the end of December, he had broken all European endurance records with an uninterrupted flight of 2 hours and 20 minutes for a distance of 77 miles. For the first time, European flyers realized that they had ignored proper controls at their own peril. One veteran pioneer was heard to remark: "Well, we are beaten! We just don't exist."

Wilbur impressed his viewers with two important features in his flying. He had complete mastery of flight control and maneuver with his combined warp and rudder operation. And with his sophisticated geared-down propellers, he achieved maximum thrust as opposed to the weak momentum provided by the crude direct-drive "paddles" used by European aviators. The obvious result was a revolution in European aviation and the emergence of the powered airplane as the world's new practical transportation medium.

From this point on, the pace of aviation progress quickened, and an international race was under way for air superiority. Overland flights one after another set new records for speed, altitude, and length of time aloft. Over water flights brought even greater changes in aircraft design. Although European pioneers acclaimed the Wrights' superiority in flying, they were slow to adopt the idea of unstable machines. They left no doubt that they had learned the lesson of proper lateral control. Farman, Bleriot, and Levavasseur began fitting their planes either with ailerons or with some form of warp control. Only Voisin continued to make planes with no form of lateral control.

By 1909, a number of record making flights and events demonstrated just how far the airplane had advanced. One of the most outstanding flights of the day was the first crossing of the English Channel by Louis Bleriot (Fig. 26). For this flight of 30 minutes, Bleriot flew what was to become the classic monoplane of early aviation, his Bleriot XI. This was the first airplane with features that resembled the single-engine monoplanes of today. This plane had a wing span of 23 feet and a four-blade tractor propeller driven by a 28 horsepower engine. It was the first fully successful European example of wing warping. In addition to wing-warping controls, it featured two rear **elevons*** on either side of the tail unit, a balanced rudder, and a small fixed fin above the center section of the tail unit to improve longitudinal stability. The elevators, rudder, and stabilizers were located behind an enclosed cockpit. It had a tricycle undercarriage.

Less than a month after Bleriot crossed the English Channel, the world's first international air meeting was held at Reims, France, on

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* An airplane control surface combining the functions of an elevator and an aileron.

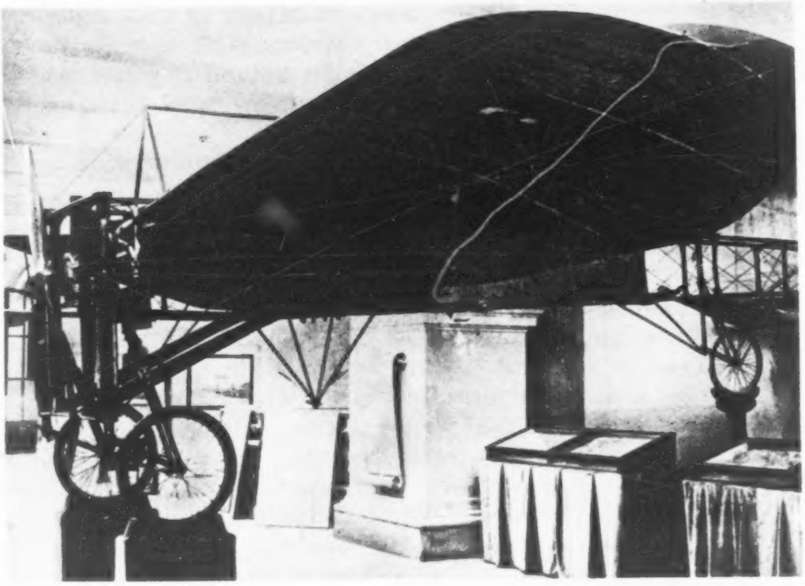

Figure 26. The Bleriot monoplane, flown by Louis Bleriot across the English Channel in 1909, was a direct forerunner of the modern monoplane.

22 August 1909. Bleriot won public acclaim with his flight across the Channel, but this meeting provided the greatest technical stimulus to aviation. Except for the Wrights, pilots and aircraft builders from France, the United States, Great Britain, and Germany were represented. Not only were all the world's most efficient aircraft on display but also several copies of each type. In all, 36 planes competed in the contest. Five had been manufactured by the Wright brothers and four by Bleriot. Other entries included 11 Voisins, 4 Antoinettes, 4 REPs built by Esnault-Pelterie, 2 Farmans, 2 Ariels, 1 Breguet, 1 Klytymans, 1 Fernandez, and 1 Curtiss. Before this meeting, only a few people had seen more than one plane in the air at a time. More than a quarter million people watched as daring pilots set world records. In an Antoinette, Hubert Latham flew to an altitude of 508 feet; Henri Farman set an endurance record for staying in the air for more than 3 hours; and Bleriot achieved the highest speed for a single lap—47.8 miles per hour. James Gordon Bennet, publisher of the *New York Herald*, had offered a prize for the fastest two laps around a triangular six and one-half mile course. A previously unknown American, Glenn

Curtiss, won this prize on the last day of the meet when he averaged 47 miles per hour.

So popular had flying become in Great Britain that the London *Daily Mail* offered $50,000 in gold for the first flight from London to Manchester, England, in less than 24 hours. Two contestants competed for the prize—Claude Graham-White of England and Louis Paulhan of France. At sunrise on 23 April 1910, Graham-White took off from a field near Willesden Junction in a Farman biplane powered by a 50-horsepower radial engine. He flew to Rugby, 85 miles away, in two hours and five minutes, a record-breaking cross-country flight. An hour later, he took off for Crewe, but engine trouble forced him down near Lichfield, 117 miles from London. Rising winds made it impossible for him to continue.

On 27 April, Paulhan arrived at Hendon with a crated biplane. He quickly assembled his machine and, at 5:30 in the afternoon, took off for Manchester. His wife, his mechanics, and a group of friends drove to Willesden, where a special train with a whitewashed roof was waiting to guide Paulhan on his way. An empty gas tank brought him down at Lichfield where he landed under cover of darkness. In one hop, he had flown 117 miles—as far as Graham-White had flown in two hops.

Within an hour of Paulhan's takeoff, Graham-White learned that the Frenchman was on his way to Manchester. In spite of efforts to change his mind, Graham-White set out immediately to overtake his rival. After traveling 60 miles, he came down at Roade at five minutes before eight. When he learned that Paulhan had already flown to Lichfield, he decided not to wait for daylight. At 2:30 in the morning, he again took off. He followed the railroad to Weedon, lost it, and then picked it up again. A friend had the lights of his automobile shining on the walls of an inn near the village of Crick. Graham-White had no trouble identifying the headlights of the car. Then the driver started moving down the road at high speed, hoping to act as a guide. But, after following the car for a mile or so, Graham-White spotted a freight train moving in the right direction and followed it. He flew over Rugby but was forced down near Polesworth by gusty winds. It was 4:14.

Five minutes earlier, Paulhan had taken off from Lichfield, and, at 5:32, he landed at Didsbury, a suburb of Manchester. His actual flying time for the 185 miles was four hours and two minutes—an average speed of more than 45 miles per hour. He won the $50,000, but only by the narrowest of margins.

Throughout the years just prior to World War I, the airplane continued to spread its appeal to increasing numbers of people. Each year saw new records for speed, altitude, and distance as airplanes in Europe and the United States improved in performance and reliability. It was an age of daredeviltry and adventure as great crowds of people thrilled at night flying, aerial acrobatics, and endurance flights.

In 1911, a Bleriot monoplane flew a 1,000 mile circuit of Great Britain in 22 hours. In the same year, another Bleriot monoplane flew nonstop from London to Paris in four hours, and, in the United States, such men as Glenn Curtiss, H. N. Atwood, C. P. Rodgers, and others were matching European achievements. Atwood flew 1,266 miles from St. Louis via Chicago to New York in 28 hours and 53 minutes, and Rodgers made the first transcontinental flight of about 4,000 miles from New York to Long Beach, California. Despite 49 days and 15 crashes en route, his flight served as a challenge for other pilots to prove their flying skills. Glenn Curtiss not only introduced the world's first practical seaplane but also saw one of his pilots make the first landing of an airplane on the deck of a ship (Fig. 27). By the time war broke out in August 1914, international records for speed, altitude, and distance without landing stood respectively at 127 miles per hour, 20,000 feet, and 635 miles.

Aviation Before World War I

The story of the airplane from the Wright brothers, historic flight to the outbreak of World War I is one of successive improvements in re-

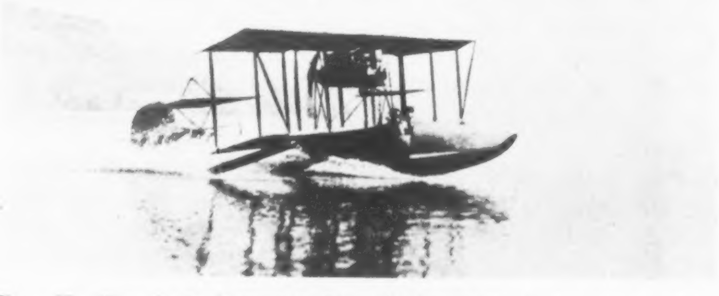

Figure 27. Glenn Curtiss demonstrates the world's first practical seaplane in San Diego harbor on 17 February 1911.

liability, performance, and comfort. The Wrights were just barely able to raise themselves from the ground in their first *Flyer*. Their persistent research in stability, control, and engine improvement produced a practical airplane.

Even in the comparatively short period of 11 years, the airplane changed rapidly from its original configuration. One of the most noticeable developments, perhaps, came with the addition of a body or fuselage. On the original Wright biplane, the pilot lay prone on the lower wing to one side of center, with the engine on the other side for balance. By 1908, the pilot sat upright on the wing in the same position. As airspeed increased, the enclosed cockpit became necessary for the pilot's comfort; its aerodynamic advantages were not generally appreciated until later.

The Bleriot XI monoplane of 1909 featured a definite improvement in the pilot's position. He was now partly enclosed in a body formed by fabric stretched over the front part of the body or fuselage. The first covered fuselage came with the Antoinette monoplane in the same year. The first attempts at streamlining the fuselage were made in 1911 on the Nieuport monoplane. The completely enclosed fuselage first appeared on a tractor biplane just prior to the outbreak of war. French engineers introduced one of the most important structural innovations in 1912 with the design of the **monocoque fuselage.*** This was a fuselage built in the form of a shell with no longitudinal stiffening as opposed to the framework fuselage either left open or partially covered with wood or fabric. The Deperdussin-Bechereau was one of the most radical monoplanes of the period. It had a plywood shell fuselage, thin mid-mounted wings, streamlined landing-gear struts, and a 140-horsepower engine (Fig. 28). One of its principal features was control of the landing wheels, indicating that designers were already thinking in terms of retractable landing gears. The French also experimented for the first time with corrugated aluminum wings and made brief flights with the first all-metal airplane in history.

This period also saw numerous experiments with the shape of the airplane, including a completely circular wing. The biplane and the monoplane gradually emerged with the biplane the more popular of the two. Although the monoplane design provided for greater speed, the biplane was more proficient from the standpoint of structure and engineering. For example, the monoplane required a longer wing to at-

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* A fuselage constructed like a shell, the skin bearing the primary stresses.

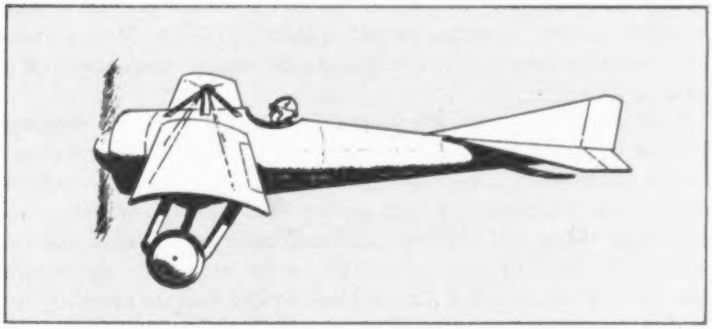

Figure 28. The French Deperdussin-Bechereau featured a plywood monocoque fuselage, aluminum mid-mounted wings, and streamlined landing-gear struts.

tain a lift even comparable to that of the biplane. With the materials then available, the larger surface of the monoplane wing meant not only added weight with external bracings but also increased air resistance. The biplane, on the other hand, was more stable and easily flown with one wing placed above the other and tied with struts and wires.

Other significant changes occurred in the control surfaces of the airplane. The Wright biplane presented an unusual appearance with its elevators in front of the wings. The Bleriot and the Antoinette monoplanes forecast modern practice with their control surfaces to the rear of the wings and propeller. An important aerodynamic principle helped to produce this change. The speed of the **slipstream*** from propellers increases the total speed of air over the tail surfaces of an airplane. Thus, the force of air upon a control surface of a given size and shape is greater behind the propellers than in front. To produce the same control force, a forward control surface must obviously be larger than one in the slipstream. The simplest solution was to shift the control surfaces from the front of the airplane to the rear.

As mentioned earlier, the Wrights achieved lateral control of their biplane by warping the wings. Most of the early airplanes, including the Bleriot XI, used this type of control. Movable surfaces (ailerons) at the wing tips were first used on the Farman biplane of 1910. All modern aircraft use ailerons. They are hinged rear portions of the wing tips which, by moving them up or down, increase or decrease lift at a given wing tip. This enables the pilot to bank or turn his aircraft without the risk of stalling.

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* The turbulent flow of air driven backward by a propeller or propellers.

Although the early Wright machines used skids and made no allowance for landing shock, their natural resilience was sufficient to absorb landing stress. Stretched elastic cords on the Bleriot XI absorbed part of the load during landing. Most of the early airplane designers relied on similar cords and pneumatic tires to absorb shock. As speeds increased, the cords were covered with streamlined casings to reduce air resistance. Later models replaced rubber shock absorbers with hydraulic types of absorbers.

Despite these and other improvements, pilots still had to fly "by the seat of their pants." Even after ailerons replaced wing warping, raising the left wing for a turn lowered the right wing and often caused the plane to skid. A pilot had to remain constantly alert and swing the rudder to avoid plunging to earth. A single loose bolt could mean a broken neck. Every pilot carried his own sewing kit, hammer, and pliers to repair his "flying crate" and keep it airborne. In a very real sense, early pilots were airborne cowboys, skilled mechanics, and bold adventurers who cajoled and coaxed their aerial horses through the air despite the perils at hand.

Thus, as the war clouds gathered in 1914, the airplane had advanced from a simple toy to a fairly reliable flying machine. The 50-horsepower engine had replaced the rail and derrick takeoff device of the Wright brothers. The propellers moved to the front for better control over rear tail surfaces, and pilots flew in enclosed fuselages. Pilots made increasing demands for more inherent stability, however. Engineers began to experiment with all-metal frames and **internally braced wings.*** They designed **radial engines**** to reduce the weight of water cooling. They simplified control by using one stick to control different surfaces. Pilots called it the "joy stick" because it was so easy to operate.

War departments demanded airplanes that would be stable under all conditions. Engineers then placed horizontal stabilizers on the rear of the airplane and tilted them forward to prevent pitching. They hinged an elevator to the stabilizer to move the tail up or down and control the angle of the wings. They added a vertical fin to control the direction of flight and attached a movable rudder to control turns in coordination with ailerons. But, with war approaching, this still was not enough. A teenager by the name of **Lawrence Sperry** believed that he could adapt the gyroscope used to stabilize his father's ships to the airplane. A Curtiss plane was equipped with the world's first automatic pilot just before the war started.

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* Wings with braces on the inside.
** See page 112 for a detailed description of radial engines.

AVIATION AND WORLD WAR I

When war broke out in 1914, the general public still regarded the airplane as a potentially useful but often treacherous toy. A number of significant events and technical changes had made it unmistakably clear that aviation was rapidly coming of age. But, in general, people were only beginning to recognize the practical value of the airplane. Although thousands of people in the United States and Europe watched in amazement as the pioneers of flight demonstrated their machines, only a small number had themselves taken to the air. In the United States, there were perhaps a half-dozen small aircraft manufacturing shops producing mostly experimental products for exhibition pilots and sportsmen.

Although various branches of the military in France, Great Britain, the United States, and Germany had experimented with armed planes, the airplane as a combat weapon had not been recognized. A British secretary of war had remarked in 1910: "We do not consider that aeroplanes will be of any possible use for war purposes." Others, including the Wright brothers, believed that the airplane would prevent war. Orville Wright wrote regretfully in 1917 as follows: "When my brother and I built and flew the first mancarrying flying machine, we thought that we were introducing into the world an invention which would make further wars practically impossible." Only a few realists managed to develop airplanes for wartime use. Although France had built 2,000 planes, a scant 200 of them were adapted to military use. Germany had secretly built about 1,500 Albatros biplanes and Taube monoplanes for spying purposes. Great Britain had approximately 180 BE–2 biplanes that had been designed by Captain Geoffrey de Havilland, who later founded his own aircraft company. The United States had only 55 Wright and Curtiss biplanes. When this country entered the war in 1917, the Aviation Section of the U.S. Army Signal Corps had fewer than 250 aircraft.

The Early Role of Military Aircraft

In the early stages of the war, pilots viewed their assignments more as pleasure flights than as the deadly business of combat. When enemy pilots crossed paths in the skies, their first inclination was to wave companionably and go about their business. Not until a British pilot reported a huge German force massed for a flank attack on British positions in France did the airplane present itself as a potential weapon. In this instance, an humble biplane had prevented a crushing British defeat and had saved Paris from the German army.

In its wartime role, the airplane developed according to the duties expected of it as the war progressed. At first, both sides used the airplane for observation of enemy positions and activities. The demand was for slow, stable aircraft that allowed pilots time to study and photograph ground activities. Radios soon became a part of the airplane's cockpit equipment, and pilots added spotting for the artillery as another responsibility. Then came orders to prevent enemy pilots from returning to their home bases with reconnaissance reports. Rather than kill their fellow aviators, many pilots dangled bricks at the end of long ropes and hurled them into the propellers of enemy planes. Only a few attempts were made to bomb enemy positions. One German lieutenant dropped small bombs by hand on the outskirts of Paris. Three British AVRO 504s staged the first long-range bombing strike in history in November 1914 when they raided Zeppelin sheds at Friedrichshafen, Germany. The Germans retaliated by sending bombing squadrons on night raids behind the Allied lines.

Speed and climbing ability became increasingly important as antiaircraft fire improved and as pilots had to defend themselves from attacks by enemy planes. This led to the development of fast maneuverable planes to defend reconnaissance aircraft, observation balloons, and, later, bombers. From fast single-seat scout planes came even faster single-seat fighting scouts, or, simply, fighters. The most notable of these single seaters were the British all-metal Sopwith Tabloid monoplane, the French Morane-Saulnier monoplane, and the Neiuport biplane (Fig. 29). The Germans used several heavy biplanes, principally the Fokker monoplane or Eindecker, for observation and military spotting. For intelligence missions, they used the Albatros and the Taube.

For months after the start of the war, arms carried by these early planes were incredibly primitive. Some pilots carried rifles, hand revolvers, and even shotguns. One member of the British Royal Flying Corps mounted a cavalry carbine on the side of his fuselage and pointed it outward at a sufficient angle to clear the propeller. So remarkable were his efforts at flying with one hand and firing at Germans with the other that he received his country's highest military award—the Victoria Cross. Accurate shooting at an angle from a mov-

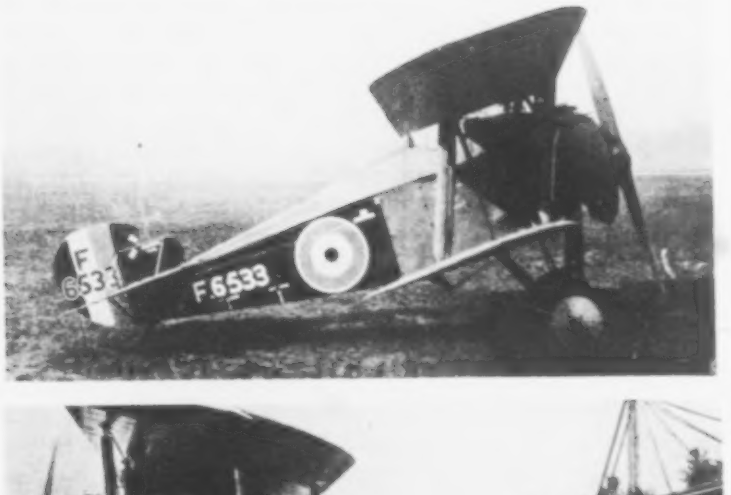
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Figure 29. Single-seat fighting scout planes in use at the beginning of World War I.

ing airplane at another airplane was beyond the ability of most pilots, however. Pilots pressed their demands for an airplane equipped with a gun that could be aimed straight ahead. This meant the development of a gun that would fire directly through the airplane's propellers.

Finally, in 1915, a French pilot named **Roland Garros** mounted an automatic rifle directly behind the propeller of his Morane monoplane. Realizing that some bullets would strike the propeller, he placed triangular steel deflectors on the back side of the propeller. Although he played a kind of airman's Russian roulette each time he fired the gun, Garros scored victories over five German airplanes in a period of 16 days and became the first Allied air "ace" of the war. Engine trouble finally forced him to land behind enemy lines, and the Germans came in possession of his armored propeller.

They immediately employed the services of Europe's most brilliant airplane designer, **Anthony Fokker,** to improve Garros' device. After studying the propeller and a German machine gun, Fokker recognized at once that random firing through whirling propeller blades was unsatisfactory. His problem was to synchronize the firing of the machine gun with the revolutions of the propeller. In two days, he developed a rod-and-lever mechanism with an interrupter gear that allowed the gun to fire only at safe intervals. With this device, he revolutionized air warfare and made the airplane a maneuverable piece of artillery.

As the war came to a stalemate in the trenches crisscrossing France, vicious air battles took place overhead with neither side able to gain a decisive advantage. The tide of battle ebbed and flowed as men on both sides searched for more powerful and destructive weapons. Airplanes were equipped with tracer bullets for the time in 1916 and later with rockets. Seaplanes and flying boats came into use for bombing and torpedo attacks. As bombs increased in size, special bombing planes with bomb racks, sights, and release mechanisms became necessary. By the end of the war, giant multiengine bombers were conducting day and night raids deep inside enemy territory.

Effects of War on Aircraft Design

With the exception of the **synchronized machine gun,** few changes were made in the design of airplanes during the early part of World War I. The major requirement was for slow, stable aircraft. As the airplane's wartime mission changed, performance, speed, endurance, and load capability became increasingly important elements in aircraft design. The obvious result was a number of significant advances not only in the appearance of the airplane but in its operation as well.

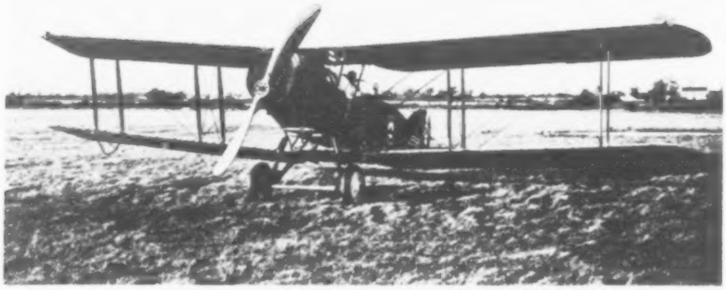

Figure 30. The British biplane was one of the most efficient two-seat fighters used in World War I.

From 1916 on, improved fighter planes came in quick succession as both sides struggled for control of the air. By the beginning of the year 1916, the German Fokker monoplane embodied several important innovations. The most noteworthy was a metal framework built of steel tubes with welded joints for the fuselage. It had a 150-horsepower **rotary engine*** and reached a top speed of 110 miles per hour. Because of inherent weaknesses in monoplane design, however, British biplanes soon overtook the Fokker monoplane (Fig. 30). The Bristol Fighter entered the war in 1917 and continued in service for many years. It had a 250-horsepower engine and flew at speeds up to 125 miles per hour. One of the most outstanding fighter planes of the entire war was the British S.E.5, the fastest and best performing plane of its day. It was so advanced that no significant aerodynamic improvements in fighter design occurred for about eight years after it appeared. Its speed and performance were due primarily to an increase of almost 100 percent in engine power, represented by its 200-horsepower Hispano-Suiza **in-line motor** (cylinders placed in a straight line, one behind the other).

This airplane had many characteristics that remained standard in biplane fighters until the monoplane reached maturity about 20 years later. In performance, it reached a speed of 132 miles per hour and climbed at the rate of 765 feet per minute. It featured a tractor propeller in front of a totally enclosed fuselage, except for the cockpit. One of its most important advances was a reduction in the number and form of bracing struts and wires used on the wings. It had one pair of streamlined struts on each side of the fuselage and oval-shaped bracing wires, both of which reduced drag. Another improvement was its staggered wings with the upper wing extending over the lower wing by about one and one-half feet. This gave it the important advantage of increased lift.

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* For a detailed description of rotary and radial engines, see page 112.

One of the most far-reaching aeronautical innovations during the war years came from a German engineer, **Hugo Junkers.** He introduced the world's first all-metal monoplane with a fully **cantilevered wing**—no outside struts or braces. After a number of experiments from 1910 until 1917, he produced a quantity of his remarkable J–4, a two-seater constructed of duralumin and powered by a 200-horsepower Benz motor. He next introduced the first low-wing cantiliver monoplane fighter which later led to a small passenger machine, the J–13, of 1919. German authorities at first feared that the high center of gravity posed by the low-wing cantilever design would adversely affect lateral stability, but their fears were groundless. Junkers adopted the low-wing configuration to reduce injuries to crew members in the event of crashes. The wings would be the first to strike the ground and would therefore absorb part of the initial shock. And when retractable landing gear were added, the low-wing position permitted short undercarriages and less weight. Junkers changed the whole course of airplane development with three vital firsts: (1) the first practical all-metal aircraft, (2) the first practical cantilever wing, and (3) the first low-wing monoplane.

Although the basic design of the airplane remained essentially the same throughout the war, a number of smaller, but significant, advances were made. For example, the British Sopwith plane of 1916 used the first workable air-brakes, or spoilers, for short-distance landing. Ingenious designers placed these spoilers at the rear of the lower center section of the wing near the fuselage. The pilot could move them vertically at right angles to the air flow and reduce his landing speed. The experimental British S.E. 4 used flaps for the first time to vary airspeed. Bubble cockpit covers came into use; **superchargers*** were applied to engines to increase rates of climb; and **two-pitch,** or **two-speed, propellers** signalled the approach of variable-pitch propellers.

With the exception of the Junkers monoplane, surprisingly little attention was given to the improvement of the airplane's structure. Most of the basic research centered on improved wing sections and highoutput engines. In both instances, major concern was the performance of fighter planes in pitched air battles. Wing sections of high lift and low drag were the natural results. Engine design advanced from small in-line and rotary types of 80- and 100-horsepower to the large water-cooled power plants of 1917 and 1918. The **rotary engines** on older aircraft revolved around the crankshaft and created serious torque problems. This made the airplane difficult to control, particularly in the heat of battle. At top speeds, the engine often caught fire, and pilots in numerous instances became ill from a constant spray of castor oil used for lubrication. The most famous engines to come out of the war were the 12-cylinder 360-horsepower Rolls-Royce Eagle VIII, the 8-cylinder 240-horsepower Mercedes, and the 12-cylinder 400-horsepower American Liberty, the most significant technical contribution made by the United States to the air war. Despite the pioneering efforts of Charles Manly, Esnault-Pelterie, and the Anzani Company, the radial engine did not become a practical form until after the war.

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* A pump or compressor for forcing more air or fuel-air mixture into an internal combustion, reciprocating engine than it would normally take in at the prevailing atmospheric pressure.

Light and heavy bombers, the forerunners of the transport plane, evolved from the slow reconnaissance planes used early in the war. The De Havilland, the most famous light bomber of the war, carried a 450-pound bombload under its wings at speeds up to 100 miles per hour. The German Gotha and the British Handley Page 0/400 flew at speeds of 60 to 80 miles per hour for 8 hours with a bombload of 1,800 pounds inside the fuselage (Fig. 31). By the end of the war, the Handley Page had grown to a giant four-engine bomber capable of delivering 7,500 pounds of bombs in a radius of 1,300 miles. Although the structural features of these and other bombers did not differ materially from the early single-seat fighters, they were the first practical multiengine airplanes.

For centuries, men had envisioned war in the air between powerful machines equipped with aerial bombs and other horrible weapons. Many, including Francesco de Lana, discontinued their experiments with flying machines when they realized their potential as weapons of war. Suddenly, in a period of less than three years, the airplane became a weapon capable of leveling entire cities. Its image rapidly changed from that of a peacetime toy to a fearful symbol of destruction. Only with the miraculous growth of air transportation in the postwar years would the airplane redeem itself in a peaceful role as a carrier of passengers and life-saving cargo.

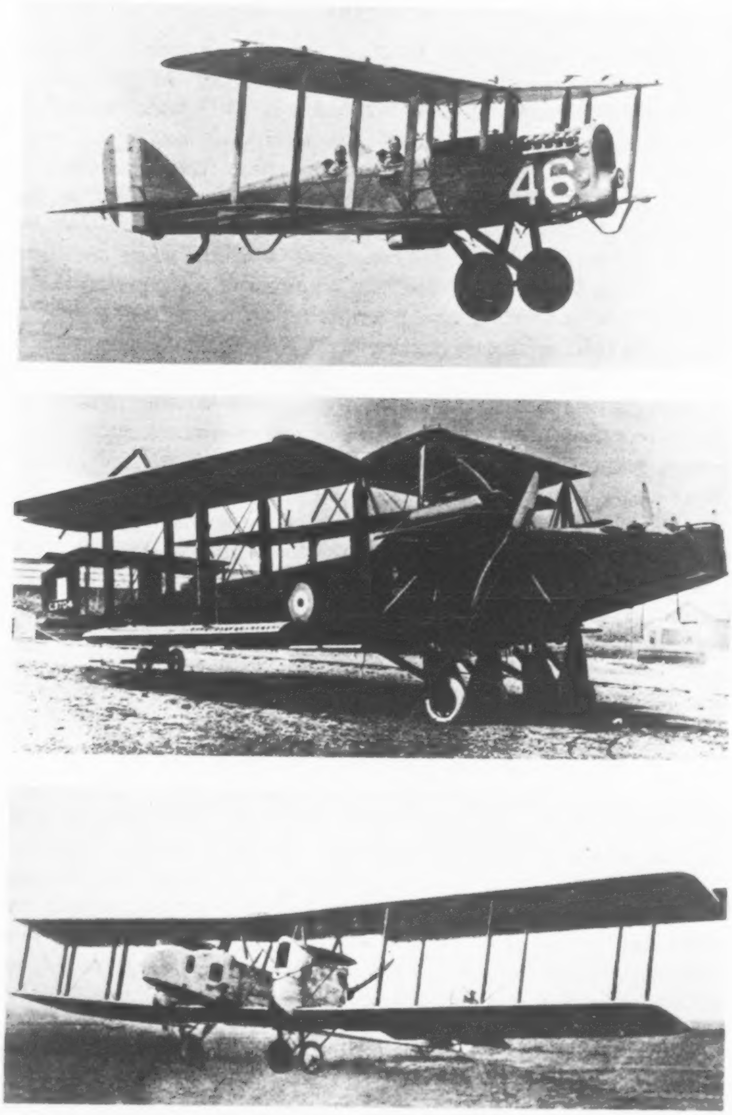


Figure 31. The DeHavilland D.H. 4 was the most famous light bomber of the war (top). The Handley Page (middle) and the Gotha (bottom) were British and German heavy bombers that flew at speeds of 80 miles per hour.

SUMMARY

It took 110 years for the practical powered airplane to advance from an idea to reality. The process began with Sir George Cayley's pioneering experiments in 1799 and ended in 1909 when the Wright brothers proved that powered flight was technically mature (i.e., contracted a sale with the U.S. Army for a practical flying machine.) In the interim, the airplane took on its modern configuration as the fixed-wing glider advanced through various stages of refinement. By the late nineteenth century, the concept of cambered wings and fixed tail units was firmly established as a requirement for powered flight. Engines with an effective power/weight ratio were still not available. One of the most significant developments prior to the Wright brothers was Octave Chanute's biplane glider.

Until the first successful powered flights by the Wright brothers, the major problems in winged flight were proper control and engine-power. Wilbur and Orville Wright based the design of their biplane *Flyer* on the achievements of their predecessors, Otto Lilienthal, Octave Chanute, and Samuel Langley, but they made a number of significant improvements in the airplane's design based on their own experiments. Their most obvious contribution to aviation was the development of an efficient engine and practical control system that enabled them to control their airplane in sustained flights under its own power. The design of a deliberately unstable aircraft was also a major factor in controlled flight because it required a skilled pilot who operated as a living and working part of his airplane.

The prospects of achieving powered flight in Europe in a controlled airplane were almost nonexistent during the early 1900s. Major interest centered on balloons and dirigibles although a small group of aviation pioneers continued to experiment with winged aircraft. The biggest obstacle was the refusal of European flyers to recognize the vital importance of effective control systems, particularly lateral control. Instead, they spent a great deal of wasted motion in their efforts to build stability into their airplanes. Following the demonstrations of Wilbur Wright in France, aviation made giant strides in Europe with France, Germany, and Great Britain taking the lead.

During the years just prior to World War I, the airplane changed rapidly from the original configuration of the Wright *Flyer*. The most obvious changes included the addition of a fuselage, the enclosed cockpit, and control surfaces. Biplanes and monoplanes became dominant types, and more powerful engines replaced the Wright brothers' rail and derrick takeoff device. Ailerons gradually took the place of wing warping, and wheeled undercarriages with shock absorbers made landing skids unnecessary.

The airplane was not recognized as a combat weapon when World War I began. It developed according to the duties expected of it as the war progressed. During the early stages of the war, both sides used the airplane for reconnaissance and observation of enemy positions. As attacks from enemy planes and anti-aircraft fire increased, pilots demanded greater speed and performance in their airplanes. Fast, maneuverable planes became necessary to defend reconnaissance planes, observation balloons, and, later, bombers from attacking aircraft. A major development was the addition of the synchronized machine gun as standard armament. By the end of the war, all fighter planes were equipped with tracer bullets and rockets. As bombs increased in size, multiengine bombing planes with bomb racks and releasing mechanisms became necessary.

Although the structural design of the airplane remained essentially the same throughout the war, there were several important innovations. The British S.E. 5, a biplane, featured a completely enclosed fuselage, fewer bracing struts, and staggered wings for greater lift. Another development was the use of air brakes, or spoilers, on the British Sopwith plane of 1916 for short-distance landing. Other developments included greatly improved water-cooled engines, more efficient wing sections, bubble cockpits, and multiengine bombers capable of delivering large loads of bombs in a radius of 1,300 miles. One of the most far-reaching innovations was the introduction by Hugo Junkers of the world's first all-metal monoplane with a fully cantilevered wing.

WORDS AND PHRASES TO REMEMBER

anhedral
bank
box-kite configuration
cantilevered wing
catapult
center of gravity
configuration
dihedral
elevon
equilibrium
fixed-wing monoplane
forward elevator
in-line motor
internally braced wings
lateral stability
longitudinal stability
monocoque fuselage
power/weight ratio
Pratt truss
radial engines
retractable landing gear
rotary engine

slipstream
supercharger
synchronized machine gun
torque
two-pitch propellers
unbraced monoplane
undercarriage
wing warping
wind tunnels

NAMES TO REMEMBER

Ader, Clement
Archdeacon, Ernest
Bleriot, Louis
Cayley, Sir George
Chanute, Octave
Esnault-Pelterie, Robert
Ferber, Ferdinand
Flyer
Fokker, Anthony
Garros, Roland
Henson, W.S.
Junkers, Hugo
Langley, Samuel P.
Levavasseur, Leon
Lilienthal, Otto
Maxim, Hiram
Montgomery, John J.
Penaud, Alphonse
Santos-Dumont, Alberto
Signal Corps Aeronautical Division
Sperry, Lawrence
Stringfellow, John
Voisin, Gabriel
Wenham, F.H.
Wright, Orville and Wilbur

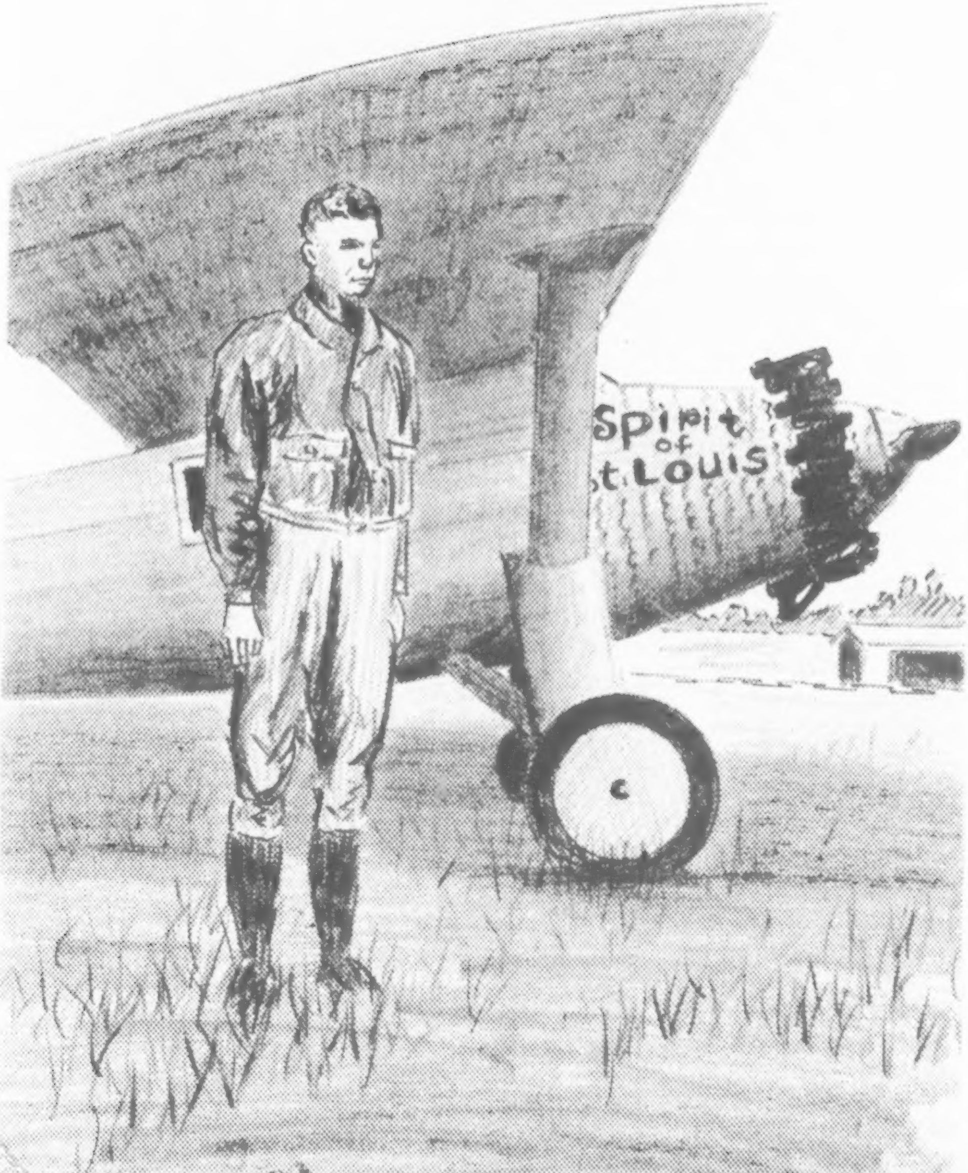
QUESTIONS

1. **Explain the basic principles underlying heavier-than-air or kinetic flight.**
2. **In what way did early air pioneers misunderstand the wing movements of birds in their search for the secret of flight?**
3. **Describe George Cayley's model glider and show how it established the basic design for modern aircraft. State the aerodynamic principles set forth by Cayley as a result of his experiments in winged flight.**
4. **What were the contributions of W. S. Henson, F. H. Wenham, and Alphonse Penaud to the Advancement of mechanical flight?**
5. **Describe the fixed-wing monoplane gliders as developed and flown by Otto Lilienthal and Octave Chanute. In what way did Lilienthal's work directly influence the Wright brothers? How did Chanute improve on Lilienthal's design for fixed-wing gliders?**
6. **How did the advent of the "horseless carriage" in the latter part of the nineteenth century contribute to further developments in aviation?**
7. **Describe the airplanes created by Clement Ader and Hiram Maxim and tell why they failed to achieve powered flight.**
8. **What were the major contributions of Samuel P. Langley to the progress of aviation in the United States?**

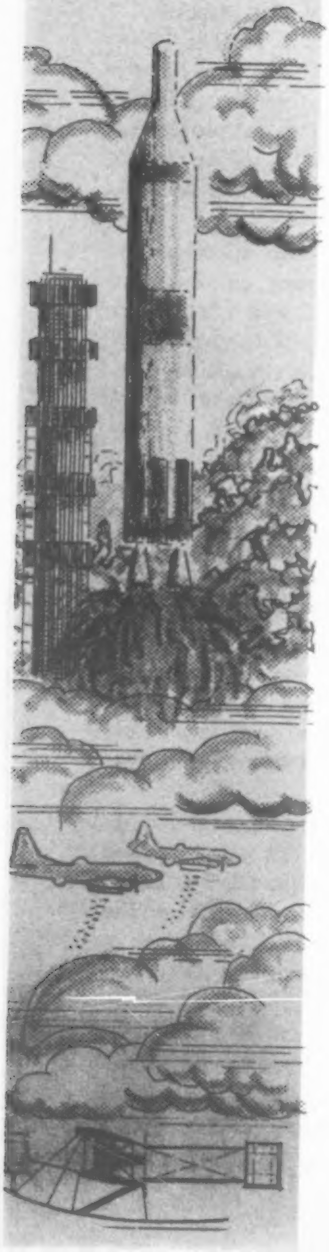
9. Discuss in some detail the work of the Wright brothers in the achievement of powered flight. What specific innovations did they contribute to airplane design? Why did they deliberately create an unstable machine?
10. Why were European air pioneers unable to achieve powered flight during the early 1900s? Describe the impact of Wilbur Wright's flights near Le Mans, France, in 1908.
11. What was the significance of the Bleriot XI, the first airplane to cross the English Channel? What other events in the same period focussed public attention on the airplane?
12. Discuss some of the most noticeable changes that had occurred in airplane design by the outbreak of World War I.
13. Show how the military role of the airplane changed as the demands of war increased. Trace the development of the synchronized machine gun.
14. What was the most significant innovation in airplane design produced during World War I? Hugo Junkers changed the whole course of airplane development with three basic innovations. What were they?
15. Discuss the evolution of the first practical multiengine airplanes.

THINGS TO DO

1. Try building a model helicopter or a "kite" glider based on the design used by Leonardo da Vinci or George Cayley.
2. Add to your scrapbook pictures of early fixed-wing airplanes and gliders that were designed or built before the Wright brothers' *Flyer*.
3. Read and report on the lives of such famous air pioneers as Octave Chanute, Samuel P. Langley, the Wright brothers, Louis Bleriot, Henri Farman, or others.
4. Continue your scrapbook with pictures of the Wright biplanes, early European airplanes, and airplanes used in World War I.
5. Construct a model of an early biplane.


Spirit
of
St. Louis

Chapter 4



Aviation Comes of Age

THIS CHAPTER covers major events in the development of the airplane in a 25-year period beginning in 1920 and ending in 1945. It opens with the story of air pioneers who risked and often lost their lives blazing trails through the skies and, in the process, added a third dimension to man's transportation systems. In addition to the feats of the "barnstormers," a number of outstanding pioneer flights proved that the airplane was rapidly coming of age. The chapter continues with a discussion of commercial aviation and its impact on the evolution of the airplane. The concluding section points out the significant changes that had occurred in the design and structure of the airplane by the outbreak of World War II. When you have studied this chapter, you should be able to do the following: (1) describe the exploits of the "barnstormers" and the pioneers who made the world's first long-distance and endurance flights; (2) give an account of Charles A. Lindbergh's solo flight across the Atlantic and explain its importance in the progress of aviation; (3) explain the purpose of the Kelly Act, the Air Commerce Act of 1926, the McNary-Watres Act, and the Civil Aeronautics Act and their significance in commercial aviation; (4) identify and discuss the major changes that had occurred in the design and structure of the airplane since the Wright brothers' flights; and (5) explain why the DC–3 is one of the world's most famous airliners.

BY THE END of World War I, the appearance of the airplane had changed radically. Its most noteworthy additions were the cantilevered wing system, an enclosed fuselage, landing wheels, a tail assembly, and a more powerful engine. Increased speed and climbing ability had made it an effective weapon of war. Of even greater significance were the large multimotored bombers that had proven the capacity of the airplane to transport heavy cargoes rapidly over long distances. Only minor changes would be necessary to convert these huge aircraft into the world's first commercial air transports.

As outstanding as were aviation achievements from 1900 to 1920, the most spectacular progress came during a period of 25 years following World War I. This was a period when aviation came of age in the public mind. Almost 100 years before, George Cayley had prophesied the peaceful role of the airplane in these words: "We shall be able to transport ourselves and our families, and their goods and chattels, more securely by air than by water."

Eager to prove their skills and the efficiency of their machines, heroic pilots made mad dashes across continents, oceans, and the polar regions. Others took up barnstorming and stunt flying in a bold effort to dispel public fears of flying. This period saw the birth of the modern airliner and the unprecedented expansion of the aircraft industry. Revolutionary changes occurred in the shape and design of the airplane, most of which were included on the Douglas DC–3, the outstanding commercial transport of the day.

POSTWAR AVIATION

When World War I ended in 1918, progress in aviation and the aircraft industry faltered while the world adjusted to peacetime conditions. The airplane and the men who flew it suddenly found themselves ill-suited for civilian life. During the war, people did not question the combat role of the airplane, but, in peacetime, they tended to associate it with violence and death. Neither private business nor the public accepted the airplane as a reliable carrier of passengers and cargo. As a result, there was only a limited demand for surplus warplanes on sale for civilian use.

The United States alone had almost 3,000 DH–4s and large numbers of the JN–4 Curtiss "Jenny" training plane. The DH–4 was too heavy and expensive for private use. Civil airlines and the Post Office Department used only a few, and the remainder were dismantled. The Curtiss "Jenny," on the other hand, was the most popular airplane of the day, easy to maintain and fly and not too expensive (Fig. 32).

Daredevils and Barnstormers

By 1920, more than 9,500 pilots had left the US Air Service and returned to civilian life. Many of these men chose civil aviation as a career at a considerable sacrifice to themselves and their families. Only a

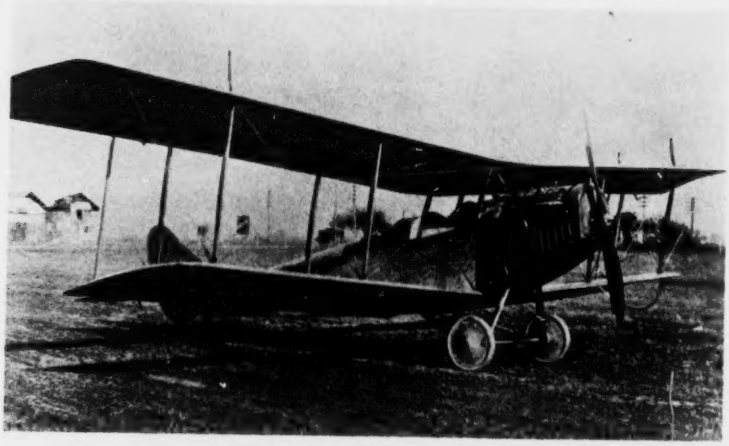


Figure 32. At the low cost of $300 to $500, the Curtiss "Jenny" was the most popular plane in operation following World War I. It was the plane used by the barnstormers for stunt flying.

few found employment with commercial airlines struggling for business with an apathetic public. Others bought surplus Curtiss "Jennies" from the Government and made their living as barnstormers. These brave adventurers flew from town to town in their weather-beaten airplanes, taking wild-eyed passengers for brief rides, giving flying lessons, or attracting crowds with daredevil stunts. For all their efforts, they earned only a meager income. One pilot stated that the greatest hazard in flying was "the risk of starving to death." Happy indeed was the barnstormer when a few brave individuals stepped forward for rides that averaged from three to four dollars each. These early air passengers did not soon forget the oily smell of roaring engines, the rush of wind, or the chilling sensation of the first steep bank.

Many barnstormers gave flying exhibitions at county fairs, carnivals, or anywhere else that crowds gathered. Several pilots often performed as a "flying circus" or worked individually with a stunt man. Their objective was to thrill their onlookers with daring tricks high above the ground. One of their favorites was "wing-walking." While the pilot flew his craft in a circle, the stunt man walked to the edge of the lower wing, climbed to the upper wing, and then returned to the cockpit. Some of the wing-walkers gave their viewers an extra thrill by standing on their heads (Fig. 33). "Breakaway" was a daring variation of wing-walking. In performing this stunt, a man walked the

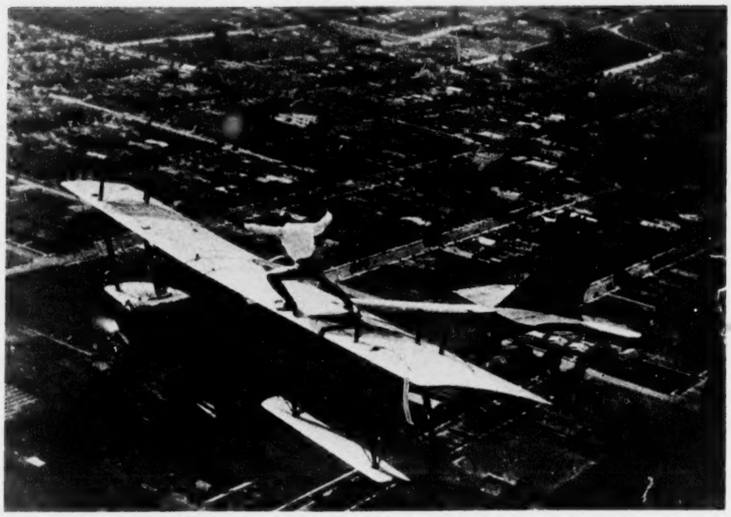


Figure 33. Wing-walking was a favorite stunt performed by the barnstormers to demonstrate the thrill of flying to the public.

length of the wing, appeared to lose his balance, and then struggled to keep from falling off. During the struggle, he would somehow manage to hang on and finally pull himself back onto the wing. From the ground, excited onlookers could not see that the stunt man wore a harness anchored to the plane by a cable. Even with these trappings, however, this stunt was difficult and dangerous. Another favorite was "plane change," a trick requiring two planes with pilots and a stunt man. When the planes were airborne, the stunt man would climb to the upper wing of his plane and wait for the second plane to fly over with a rope ladder dangling from a wing. After catching the ladder and scrambling up to the second plane, he frequently parachuted to the ground.

One of the best-known barnstormers was **Charles Lindbergh**, who performed one of the most daring stunts of the day and later made the world's first solo flight across the Atlantic Ocean. During his barnstorming days, he often stood on the upper wing of a plane while the pilot flew a series of loops. With aids not visible to his onlookers, Lindbergh appeared to stand upright on the wing while the plane flew upside down and sideways. Lindbergh's feet, of course, were strapped to the wing, and he was steadied by wires attached to the wing from his belt. As helpful as these devices were, they offered no guarantee of safety.

These "flying gypsies" did not set out deliberately to promote public interest in aviation. They flew for the sake of flying and as a means of earning a livelihood. Without realizing it, perhaps, they performed a vital service for aviation and for the public. They publicized the airplane, restored faith in the future of aviation, and brought romance to flying when public interest lay elsewhere. Many people had never seen an airplane, and, even when they thought of aviation, their first reaction was frequently one of fear and disapproval. Although the barnstormers and their air shows may not have completely eliminated public fear of the airplane, they certainly did create widespread public interest in flyers and flying.

Some Famous Pioneer Flights

In addition to the barnstormers and their flying circuses, a number of dramatic long-distance flights during the 1920s and early 1930s proved that the airplane was coming of age. As early as 1913, the London *Daily Mail* had made a standing offer of $50,000 to the crew of the first airplane to make a nonstop crossing of the Atlantic Ocean in 72 hours or less. The first attempt to win the prize came in 1919 when **Harry Hawker** and **Kenneth McKenzie-Grieve** took off from Trepassey, Newfoundland, in a specially designed British Sopwith plane with a 350-horsepower Rolls-Royce engine. They were little more than half way to their destination when engine failure forced them to land in the icy waters of the north Atlantic.

Meanwhile, the US Navy had ordered four new biplanes from the Curtiss Engineering Corporation for delivery late in 1918. These planes became known as the NC (Navy-Curtiss) series designed especially to make the first trip by air across the Atlantic. A hangar fire forced the retirement of the NC–2, leaving three to fly in the transatlantic unit. With four 350-horsepower American Liberty engines, the NC flying boat was the largest plane of the day. It had a wing span of 126 feet and weighed 28,000 pounds with a crew of six and 1,200 gallons of fuel. Unlike the flights for the *Daily Mail* prize, this flight was planned in three stages: from Rockaway, New York, to Halifax, Nova Scotia; to Trepassey, Newfoundland; to the Azores; to Lisbon, Portugal; and then to Plymouth, England. The total planned distance was 3,130 miles.

The planes took off from Rockaway on 8 May 1919 and arrived without difficulty at Trepassey. The next stage, of course, was the cri-

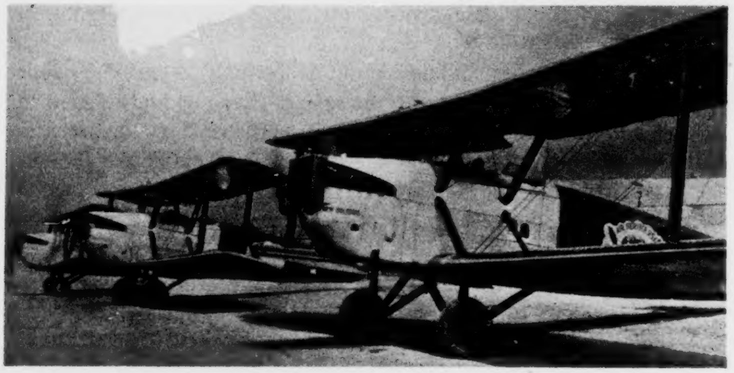


Figure 34. The NC–4 was the first airplane to make a west to east transatlantic crossing.

tical one—the long hop to the Azores, 1,200 miles over water. As a safeguard, naval vessels took positions 50 miles apart along the proposed route. Of the three planes that left Trepassey on 16 May, only the NC–4 made the complete trip. On the second day over water, a thick fog forced the NC–1 and the NC–3 to land on the water. The NC–1 was badly damaged and sank; the NC–3 could not take off in the heavy sea. The crew taxied the plane for three days over 200 miles of rough water to Horta, Azores. The NC–4 continued its journey by way of Lisbon, Portugal, and landed at Plymouth, England, near the spot where the Mayflower had moored 300 years before. It took them 23 days to cover a distance of 3,936 miles from Rockaway, although they were in the air for only 52½ hours. This was man's first transatlantic crossing by air (Fig. 34).

The glamor of the NC–4's achievement was quickly overshadowed in June 1919 when two British pilots, **John Alcock** and **Arthur Whitten-Brown,** set out to win the *Daily Mail* prize. They flew a remodeled twin-engine Vickers-Vimy bomber nonstop across the Atlantic from St. Johns, Newfoundland, to the coast of Ireland, a distance of 1,936 miles in 16 hours. (The NC–4 had taken 23 days.) Although they made a crash landing in an Irish bog, they won the prize of $50,000. These transatlantic flights in 1919 showed just how far the airplane had advanced since the first flights of the Wright brothers in 1903. Before the decade ended, however, restless air pioneers tested the airplane's ability in even more dramatic flights.

No one had attempted to cross the United States by air since Calbraith Rodgers made his 49-day flight in 1911. Two Army lieutenants,

John Macready and **Oakley Kelly,** made two unsuccessful attempts in 1922 to fly nonstop from San Diego to New York. They failed the first time because of bad weather, and, on their second attempt, a leaky radiator forced them to land at Indianapolis, Indiana, three-fourths of the way to their goal. In May 1923, they took off from Roosevelt Field, Long Island, in a Fokker T2 with a 400-horsepower Liberty engine. They made a nonstop flight of 27 hours and 2,500 miles to Rockwell Field, San Diego, California. The following year, Army Lieutenant **Russell Maughan** raced against the sun from Long Island to San Francisco in 17 hours and 52 minutes. He averaged 150 miles per hour, and, when he landed at sunset, he gave the mayor of San Francisco a copy of *The New York Times* printed that morning.

While Maughan raced the sun across the United States in 1924, three Army planes approached the halfway point in the most ambitious aerial exploit yet undertaken. They were making man's first mass flight around the world. They were biplanes especially designed by the Douglas Aircraft Company to fly both as land planes and seaplanes. They measured 50 feet from wing tip to wing tip and carried a 450-horsepower Liberty engine. On the last leg of the trip, one plane was lost between the Orkney Islands and Iceland and another in Alaska. The remaining two covered a total airline distance of 26,435 miles 175 days after they took off from Seattle, Washington.

Throughout the decades of the twenties and thirties, the airplane continued to thrill the world with other record-making flights. In 1924 and 1925, a British pilot, Alan Cobham, made round trip flights from London to Rangoon, Burma, and Capetown. His pioneering efforts resulted later in a commercial air network linking Great Britain with her far-flung empire. In 1926, **Richard Byrd** earned world recognition for the United States when he made man's first flight over the North Pole. He made his flight to the North Pole in a Fokker monoplane equipped with three Wright Whirlwind engines. The expedition to the South Pole included three Loening amphibian planes and one three-engine, all-metal Ford monoplane. As sensational as these flights were in stimulating public interest in aviation, a young barnstormer named Charles A Lindbergh made one of the most widely publicized flights of the century in 1927.

Some seven or eight years before Byrd's polar flights, a wealthy flying enthusiast, Raymond Orteig, had offered $25,000 for the first nonstop flight from New York to Paris. The success of the US Navy's NC–4 and Alcock and Brown's Vickers-Vimy took some of the attraction from the idea of a transatlantic flight. The expense and hazards of such a flight seemed to outweigh the potential rewards. The problem was not that wings were fragile or that men lacked the courage; engines simply were not sufficiently reliable to operate continuously for such distances. But, by 1927, the airplane had proven itself to be a reasonably dependable machine. In addition to improved design, it now had instruments for more accurate navigation and a higher quality of oils and fuels. One of the most important new developments was a 220-horsepower, air-cooled Wright Whirlwind engine. This radial engine had already proven itself unexcelled for long-distance flights in Richard Byrd's expedition to the North Pole.

At the time of Byrd's flight, Lindbergh worked as an airmail pilot with the Robertson Aircraft Corporation in St. Louis. He had already logged 2,000 hours in the air, but his ambition was to compete for the Orteig prize. He believed that the new Whirlwind engine would pull a carefully designed monoplane across the 3,300 mile stretch of land and sea between New York and Paris. With $2,000 of his own savings, he contacted a group of businessmen in St. Louis who agreed to raise $13,000 for a new monoplane.

Unable to reach an agreement with Fokker and other aircraft manufacturers, Lindbergh turned to the relatively unknown Ryan Airlines Company in San Diego. Realizing that others were also contending for the Orteig prize, Lindbergh and the Ryan factory staff completed the new Spirit of St. Louis monoplane in 60 days. On 10 May, Lindbergh made a nonstop flight from San Diego to St. Louis in 14 hours and 25 minutes and arrived in New York two days later. On this trip, he established a new transcontinental flight record—21 hours and 20 minutes flying time from San Diego to New York. He was now ready for his main objective—a nonstop solo flight from New York to Paris.

After a week of waiting for favorable weather conditions, Lindbergh finally prepared for takeoff on the morning of 20 May 1927. At the moment of takeoff, however, only the weather conditions were favorable. The runway was soggy and rainsoaked, and the plane was overloaded. Only after he was airborne did he breathe a sigh of relief.

His course took him along the New England coast and over Labrador and Newfoundland. At sunset, he left land and set out over the Atlantic into a night of high winds, sleet, rain, and fog. Twenty-seven hours after he had taken off, he sighted several small fishing boats on the water below. He circled low, cut his engine, leaned over the fuselage, and shouted, to the amazed fishermen, "Which way is Ireland?" He had nothing to worry about because he was on course and two hours ahead of schedule. His instruments guided him within three

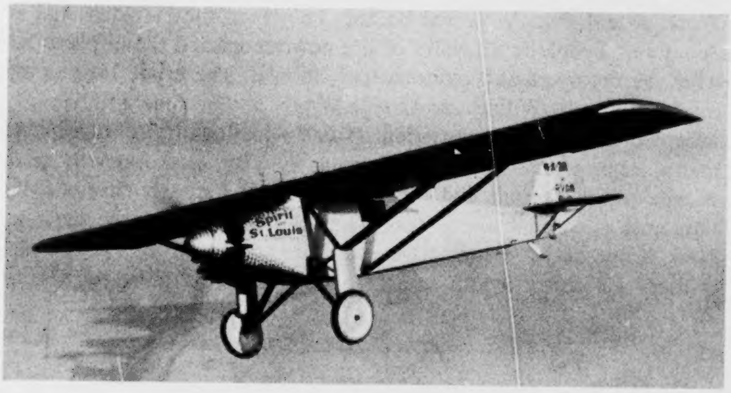


Figure 35. Charles A. Lindbergh made the most famous flight of the century in 1927 when he made the world's first nonstop flight from New York to Paris.

miles of a predesignated point on the Irish coast. He winged across the Irish Sea to the southern tip of England and over the English Channel to France. He landed at Le Bourget airport outside Paris after a flight of 3,600 miles and 33½ hours flying time. Even today when modern jets cover the same distance in less than one-third the time, Lindbergh's flight remains one of the greatest individual accomplishments of all time (Fig. 35).

Not only was Lindbergh treated royally in France, Belgium, and England, but he returned home to a tremendous welcome by his own countrymen. Between 20 July and 23 October 1927, he made a 22,350 mile nationwide tour of the United States in the **Spirit of St. Louis.** On this tour, he spoke in 72 cities, promoting aviation and urging the construction of municipal airports. Later in the same year, he made a 3,200-mile Pan American tour, beginning with a nonstop flight from Washington, D.C. to Mexico City. From this point, he flew to the capitals of Central America, several countries of South America, and the West Indies, returning nonstop from Havana to St. Louis. More than any other single flyer of his day, Lindbergh provided the stimulus that led to fantastic developments in American aviation during the coming years.

The famous pioneer flights included in our discussion are only examples to illustrate the growing popularity and importance of the airplane in American life. So numerous were the flying activities and pioneering efforts of dedicated airmen during two decades following

World War I that the period became known as the "Golden Age of Aviation." People in all walks of life now recognized the airplane for what the dreamers and pioneers had claimed. The crude little flying machine built by Wilbur and Orville Wright had become a universally accepted mode of transportation. It had added a third dimension to man's transportation system. It could fly over land barriers, span oceans, compress time, and shrink distances. In the early days of aviation, only a few bold adventurers believed in the future of the airplane. Now, it was only a matter of time and money before commercial and military air power would assume a dominant role in world affairs.

THE AIRPLANE AND THE PUBLIC

During the years immediately following World War I, Europe led in the development of passenger-carrying airlines. Strangely enough, Germany first entered the field less than three months after the Armistice with a small company known as the Deutsche Luftreederie operating between Berlin, Leipzig, and Weimar. Four airlines operating in Great Britain during the early twenties merged in 1924 into a system known as BOAC (British Overseas Airways Company). Five companies in France provided passenger service, mainly to London. In most instances, both British and French companies flew converted bombers or observation planes that had been used in the war. The two most noteworthy companies in the United States were the Curtiss Engineering Corporation and Aeromarine.

By 1926, European airline companies had carried more than 100,000 passengers for a total distance of approximately 9 million miles. Passenger travel in the United States had a much slower beginning. A number of problems were responsible. For one thing, surplus warplanes, such as the DH–4s, were not sufficiently reliable to cope with the great distances and rugged terrain in the United States. And, as mentioned earlier, public apathy toward the airplane caused businessmen to view commercial aviation as a poor investment. Even among well-established aircraft companies, low passenger revenues and high operating costs stifled private initiative. In 1920, for example, the Aeromarine Company reported: For every $100 spent, insurance, depreciation, and sales promotion took 69 percent, fuel and labor 15 percent, and maintenance 16 percent. Without subsidies similar to those paid by European governments to their fledgling airlines, this company, like a number of others, soon faded from the commercial air transport picture.

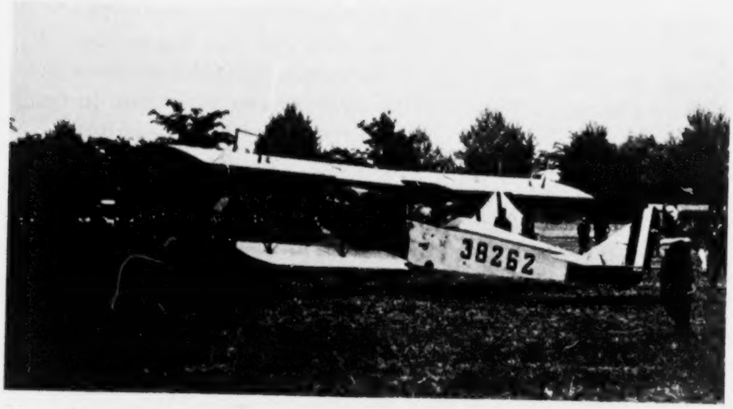


Figure 36. The first airmail flight between Washington and New York ended on a Maryland farm 25 miles south of Washington.

Mail Delivery on Wings

Air transportation as a commercial enterprise had its beginning in the United States with the carrying of the mail. Before World War I, the US Post Office Department had attempted to establish airmail routes in certain areas where delivery by air would have been more economical. Congress did not allocate funds for an airmail service at that time, however. During the war, the Army decided that regularly scheduled cross-country flying would provide excellent pilot training for combat in Europe. Army pilots thus became the first flying mailmen on regular runs between Washington, Philadelphia, and New York. This was the beginning of the nation's first regularly scheduled public airmail service.

Following the war, Congress granted the Post Office Department $100,000 to begin an airmail transportation system. With the help of Army pilots in 1918, the Post Office opened an airmail route between Washington and New York. On the day of the first flight, a VIP inaugural crowd gathered in Washington to watch the takeoff (Fig. 36). One observer wrote this report:

> Four sacks of mail were loaded aboard the plane, but the engine refused to start for a very simple reason: its fuel tanks were empty. A nearby plane then was drained to provide fuel. The mail finally got under way but missed the route to New York and landed on a Maryland farm, 25 miles from Washington. The plane from New York to Washington made a better showing, reaching Washington in 3 hours and 20 minutes. In the first month, only one-third of the scheduled trips between these two cities were completed; flying time averaged 4 hours.

Army pilots carried the mail in Curtiss JN–4H biplanes with a mail load of 200 pounds per trip. So successful did these flights eventually become that plans were made in 1919 for an airmail route from New York to Chicago over the treacherous Allegheny Mountains. In time, pilots began to label this route the "graveyard run" because of the incredible conditions under which they flew. Not only did they fly in rebuilt warplanes with open cockpits through rain, fog, and high winds. They had no radio beams, weather stations, blind-flying instruments, or lighted air beacons. Despite numerous problems encountered on the New York to Chicago run, the Post Office Department extended airmail delivery in 1920 as far west as San Francisco.

Realizing that the airmail service could not compete with trains traveling night and day, postal authorities undertook the bold step of adapting airplanes and airports for scheduled night flying. They took the unprecedented step of establishing beacon lights at 10-mile intervals along the transcontinental run and constructed emergency landing fields approximately every 30 miles. The United States had inaugurated the world's first regular night service on a lighted airway between New York and the West coast by 1 July 1924. This day-and-night airway from coast to coast became the central point for extending regional branch lines all over the United States. As a result of this contribution to safer air travel, the US Army Air Mail Service received the Collier Trophy two years in succession "for the greatest achievement in aviation in America" during the period 1922–1923.

Although the nation had developed a transcontinental airways system by 1924, many difficult problems still had to be solved before commercial aviation would come into its own. Practically no progress had been made in two-way radio communications with planes in flight, weather reporting, or methods of coping with bad weather conditions. One airline authority reported at least a partial solution as follows:

> The Post Office officials were particularly disappointed in their failure to develop techniques to meet hazardous weather. . . . Stubborn insistence on (an all-weather flying) policy led to mounting pilot fatalities. . . . In 1921, there were 12 pilots killed in crashes, and the average life expectancy of the group was not above four years. This condition led the pilots to strike. . . . A compromise was reached whereby the station manager, rather than a distant Post Office official, was given final authority to order a flight. Thereafter operations were gradually smoothed out until by 1926 there was only one pilot fatality.

The Growth of Commercial Aviation

As airplanes and airline systems continued to improve, there were growing demands for the Government to consider contracting with private enterprise for airmail operations. Although legislation to this effect had been drafted as early as 1922, Congress did not seriously consider the problem until three years later. In February 1925, it passed the **Kelly Act** "to encourage commercial aviation and authorize the Postmaster General to contract for airmail service." This was the first official Government recognition of commercial aviation. By October of the same year, such companies as Colonial Air Transport, National Air Transport, and Boeing Air Transport were conducting airmail operations in various sections of the country. These early contractors gave only limited attention to passengers because they derived most of their operating profit from mail contracts.

Between 1926 and 1930, the Government provided two additional spurs to the development of commercial aviation. The **Air Commerce Act** of May 1926 gave the Government broad powers to build, maintain, and regulate national airways. The act created a Bureau of Aeronautics in the Department of Commerce to license pilots, develop flight safety rules, create air navigation facilities, lay out flight routes, and furnish flight information. It became known as the "legislative cornerstone for the development of commercial aviation in America." The **McNary-Watres Act** of 1930 provided further incentive for the airline industry to improve both its aircraft and its services. It encouraged the development of passenger traffic by varying mail contracts according to the steps taken by the airlines to increase passenger space and comfort. It also offered financial support to airlines that used multiengine planes equipped with the latest navigational aids.

As mentioned earlier, Lindbergh's flight created mass enthusiasm for air travel and gave the airline industry a much needed shot in the arm. Within a year, applications for pilot licenses jumped from 1,000 to 5,500 and the number of licensed planes from 1,100 to 4,700. Aircraft construction and operation became the country's most profitable investment and led to the creation of 44 **scheduled airlines*** by 1929. This, of course, produced keen and often bitter competition between rival companies for supremacy on the air transport market. Many companies merged into major transcontinental systems with such familiar names as Transcontinental and Western Air (TWA), United Airlines, and American Airways.

By 1930, people were making transcontinental air flights in 48 hours at a cost of $351.94. (Today, they make comparable flights in no more than five hours at less than half this cost.) Airline operators established basic route patterns that continue to form the backbone of the modern route structure. The development of a two-way radio telephone system by Herbert Hoover, Jr., then an engineer with the Guggenheim Foundation, brought an end to casual and haphazard signal and communications systems. Continuing competition brought major improvements in passenger comfort and safety. In 1933, the Boeing Aircraft Company introduced the Boeing 247, an all-metal monoplane that was, for all practical purposes, the first modern airliner. With two **cowled*** Wasp engines, it carried 10 passengers and reached speeds as high as 170 miles per hour. In the same year, the Douglas Aircraft Company introduced the DC–2, a twin-engine, all-metal monoplane, slightly faster than the Boeing 247. This plane carried 14 passengers and had soundproofed cabins, retractable landing gear, a galley for hot meals, and other major improvements.

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* Airlines that operate on fixed schedules.

So rapidly had aviation advanced by 1935 that 150 different companies with as many models were competing for the nation's commercial traffic. Major passenger airlines had established worldwide networks and demanded an air transport plane with a nonstop cruising range of 150 miles per hour. One company, American Airways, had planned a transcontinental sleeper service but had not found a plane that would make such service practical. It needed a plane capable of taking off from New York at sundown, flying all night with no more than four fueling stops, and landing in California the next day. It presented its problem to the Douglas Aircraft Company. In their efforts to expand the DC–2 with overnight berths for passengers, company engineers created the DC–3, one of the most versatile transport aircraft ever developed. Among many other outstanding features, this airplane brought durability, speed, and profit to the commercial market. It was capable of carrying 21 passengers in almost complete comfort, climbing above turbulent weather to an altitude of 20,000 feet, and flying a distance of 2,000 miles at 200 miles per hour. By the beginning of World War II, it had captured 90 percent of the commercial market and had carried more than 2 million people across the Atlantic.

By 1938, people viewed the airplane as a mode of transportation equally as important as the automobile and the railroad. The question now was not so much whether flying was safe and economical but whether the airplane could compete with the automobile and the rail-

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* A covering of metal, wood, or other material placed over or around an aircraft component or section for directing and regulating the flow of cooling air, for streamlining, or for protecting the part or section covered.

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road as a public transportation medium. An air-minded public demanded airplanes with the comfort of airborne palaces and of every imaginable size and speed. Just prior to World War II, more than 13,000 people worked in the air transport industry which had an annual payroll of approximately 24 million dollars.

As more and more people took to the air in high-speed aircraft, Congress passed the **Civil Aeronautics Act in 1939.** This act recognized the growing air-mindedness of the American people and called for "the encouragement and development of an air transportation system properly adapted to the present and future needs of the foreign and domestic commerce of the United States. . . ." It not only authorized the maximum development of air transportation but also outlined specific requirements for air traffic control, the operation of airways, the improvement of airports, and the creation of better aviation communication systems.

MAJOR CHANGES IN AIRPLANE DESIGN AND STRUCTURE

At the beginning of World War I, airplanes were designed to carry no more than two passengers and a pilot. During the war, major attention centered on aircraft designed for the military mission. Toward the end of the war, large, multiengine biplanes operated as bombers for carrying heavy cargoes of explosives over long distances. European airline companies modified these large bombers soon after the war and used them for some of the earliest commercial flights. Usually, the only major change necessary was to substitute an enclosed passenger cabin for space allocated to bomb storage. Even this change was not always made. In one instance, an early French airline used a converted biplane bomber to carry as many as five or six passengers in an open cockpit. The first evidence of an enclosed cabin appeared in 1919 on a French Goliath bomber. With two 260-horsepower engines and "trousered" undercarriage legs to reduce drag, this airplane reached a cruising speed of about 100 miles per hour.

As mentioned earlier, commercial aviation, as an organized business, began shortly after the end of World War I and developed rapidly in the ensuing years before World War II. Technically, the airplane passed through two well-defined phases during this period. European airlines dominated the first phase which lasted until 1933. British airlines depended almost entirely on biplanes, while French and German airlines favored monoplanes. The first major postwar im-

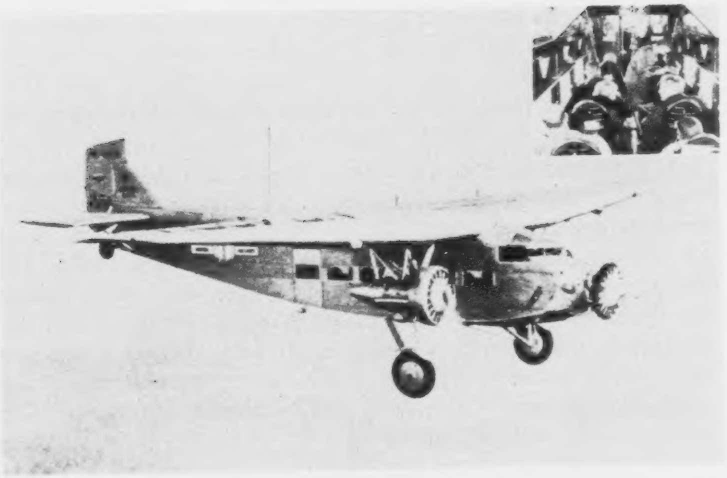

Figure 37. The Ford trimotor was a 12-passenger, all-metal monoplane and became the backbone of early US airlines. Several of these planes were still airworthy in 1970, even though they were 40 years old.

provement in the airplane came during 1924 and 1925 in Europe with the introduction of the Junkers, Rohrbach, and Fokker monoplanes.

Prior to 1933, the United States built no significant commercial aircraft. American interest centered chiefly in the construction of relatively small aircraft for carrying the mail. The first semblance of an airliner built in the United States was the Ford trimotor monoplane of 1926 based on the Junkers and Fokker design (Fig. 37). This plane reached cruising speeds up to 105 miles per hour, and, with improved American radial engines, later versions in 1928 increased this figure to 120 miles per hour. The United States assumed a leading role in the design of commercial aircraft in 1933 with the introduction of the Boeing 247, a low-wing monoplane capable of carrying 10 passengers at a cruising speed of 155 miles per hour.

The American Revolution in Aircraft Design

Civil aircraft production in the United States expanded rapidly as a direct result of increased public interest in air taxi, business, and commercial flying. The mail and air taxi business provided the initial market for small, single-engine airplanes. With this market and the availability of constantly improving radial air-cooled engines, American manufacturers began a process of improvement that made them world

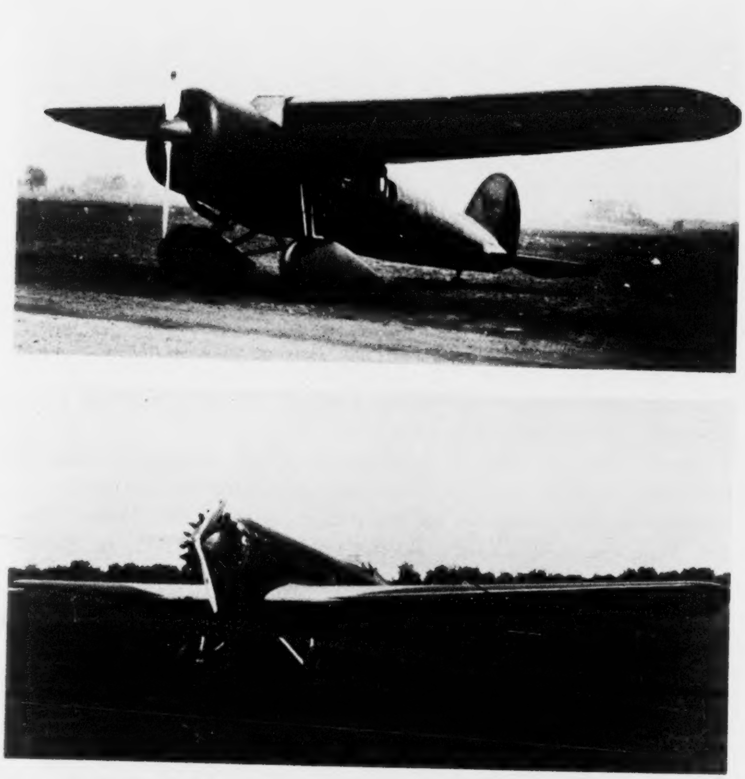

Figure 38. Aircraft design took a major step forward from 1927 to 1930 with the production of four monoplanes. The Ryan monoplane appeared first in 1927 as the best streamlined plane of the day, but it was succeeded the same year by the Lockheed Vega. The Boeing Monomail was one of the first all-metal low-wing monoplanes produced in the US.

leaders in aircraft design. The Ryan monoplane that carried Lindbergh to Paris in 1927, for example, was the best streamlined plane of its day. In the same year, however, the Lockheed Vega presented an even more advanced design. It was a high-wing cantilever monoplane that closely resembled modern designs and brought the commercial airplane a speed of 150 miles per hour. It was built of plywood covered with fabric and carried from four to six passengers. The first all-metal low-wing monoplanes in the United States appeared in 1930 with the production of the Northrop Alpha and the Boeing Monomail.

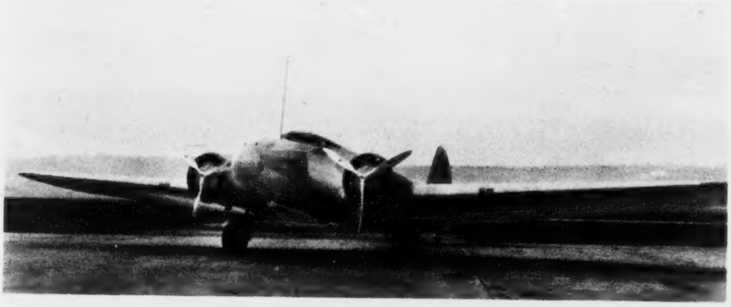

Figure 39. The Boeing 247 had two cowled 570-horsepower radial engines and cruised at 170 miles per hour with 10 passengers. It was the forerunner of the modern airliner.

The Monomail was among the first airplanes in the world with a retractable undercarriage (Fig. 38).

The Boeing 247 evolved from the Monomail through the Boeing B–9 bomber and became the first commercial transport to incorporate the improvements featured on the smaller single-engine planes (Fig. 39). With the B–9 bomber, Boeing proved that twin-engine planes were more efficient than trimotors and built the 247 as a twin-engine transport. The Boeing Company gained an immediate competitive advantage on the airline market when United Airlines ordered 60 of the 247s in 1932.

Shortly thereafter, the Douglas Aircraft Company introduced the world to the first of its DC series—the DC–2 (Fig. 40) and the DC–3. The DC–2 revolutionized airplane design, but it was the DC–3 that combined the improvements of the DC–2 into an efficient performance. By widening the fuselage on the DC–3, adding 10 feet to its wing span, and fitting more powerful engines, Douglas engineers increased the passenger capacity of the airplane to 21 and, in the process, created the most economical passenger transport in existence. Because of these innovations, the operating costs of the DC–3 were 33 percent less than those of the Ford trimotor. Except for the smaller and faster Lockheed airplanes and the larger ones produced by Boeing, the Douglas Company held a virtual monopoly on world airliners until the outbreak of World War II.

The efficiency of the DC series resulted directly from major aerodynamic and propulsive improvements. Although the all-metal DC aircraft were heavier than their predecessors, their structural design made them the most durable airplanes ever built. Their aerodynamic effi-

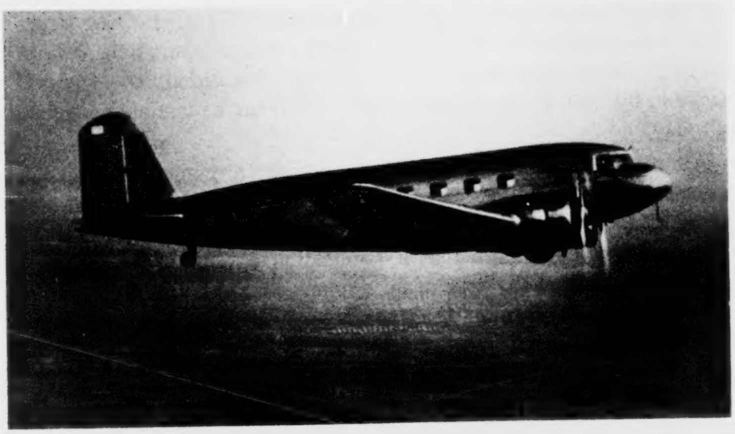

Figure 40. The forerunner of the modern Douglas DC series was the DC–2, an all-metal, low-wing monoplane that revolutionized airplane design, but it was the DC–3 shown on page 118 that made passenger transport an economical enterprise.

ciency resulted primarily from the use of the unbraced (cantilever) monoplane wing, improved streamlining, and a smaller wing area. The **variable-pitch propeller***, improved engines, higher quality fuels, and other innovations gave the DCs more propulsive efficiency than their contemporaries. These innovations and their technical significance in the design of the airplane are discussed in some detail in the following sections.

The Shape of the Airplane

The major problem facing the airline industry throughout the twenties and thirties was the high cost of operations. In the early stages of the airplane, designers concerned themselves primarily with the creation of a flyable and controllable machine. Only after a commercial market developed did the efficiency of the airplane become a primary issue. The Wright brothers, for example, were not concerned with streamlining. Their problem was to get a man-made machine in the air. The Wright Flyers and even the box-kite machines of Bleriot and Santos-Dumont were unstreamlined assemblies of different but vital parts. The first important change in the shape of the airplane came in 1910 with the Nieuport monoplane. This airplane had fewer bracing wires for its wings than other monoplanes of the period and a fuselage that resembled the modern streamlined form. The next major structural change came with the all-steel cantilever monoplane built in Germany by Hugo Junkers in 1915. Although this monoplane was too heavy to fly well, it was a further step toward the streamlined airplane of today.

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* Any propeller that can have its blade angle changed while rotating.

Almost from the beginning of powered flight, airplane designers had known that the simplest way to make the airplane more efficient was to reduce drag. As early as 1907, F. W. Lanchester had explained the importance of streamlining in a publication entitled *Aerodynamics*. His theory was that the drag of an airplane should be no greater than that created by the friction of air passing over its surface during flight. Until the late twenties and thirties, most designers, particularly those in Europe, persisted in the idea that reduced weight was more important than streamlining simply because they did not know the benefits of streamlining. It was just too difficult to build a reliable cantilever monoplane with the wood and fabric that was used in the construction of airplanes until the 1920s.

The most significant progress in the application of streamlining to the airplane came at the hands of American designers during the 1920s. The Ryan and Bellanca braced high-wing monoplanes were the best streamlined planes produced in 1925 and 1926, even with their fabric-covered metal or wooden frames. In 1927, the Lockheed Vega demonstrated the practical value of streamlining on commercial aircraft. It had a cruising speed of 135 miles per hour when 100 miles per hour was still the accepted norm. Only the absence of an **engine cowling** and the use of a fixed undercarriage spoiled its excellent streamlined fuselage.

A further step in the reduction of drag by streamlining was the addition of cowlings to radial engines. Only limited efforts to reduce the drag of the radial engine by enclosing it in a cowl were made before 1927. Designers were more concerned with adequate cooling and the accessibility of the engine for repairs. While studying the effects of a ring mounted on a streamlined airplane fuselage, a British scientist, **H. L. Townend,** mounted a ring around the cylinders of a radial engine. The result was a sharp reduction in drag. Since it left the engine exposed and did not affect cooling, British designers began using the "Townend ring" on all airplanes with radial engines. A similar cowling designed by the **National Advisory Committee for Aeronautics (NACA)** was quickly adopted for use on American airplanes. Further improvements in the engine cowling by the makers of the Pratt-Whitney engine reduced the drag on an air-cooled radial engine to that of a water-cooled engine.

In 1930, the Northrop Alpha and the Boeing Monomail with their **stressed-skin metal structures*** marked the next stage in the changing shape of the airplane. Not only did these airplanes feature the latest developments in streamlining, they were powered by two of the most efficient engines of the day—the Monomail used a 575-horsepower Pratt-Whitney Hornet and the Alpha, a 425-horsepower Wasp. Both airplanes used the NACA cowl, and the Monomail introduced a change that was to become standard equipment on all commercial airliners—a retractable undercarriage. A **wing fillet** or **fairing**** at the point where the wing joined the fuselage improved both the efficiency and handling of these low-wing monoplanes. Although fixed-pitch propellers and low wing loading limited their overall performance, these planes were convincing proof that the new airplane design was superior to the older designs.

The streamlined shape advanced a further step in the 1930s when designers decided to mount engines on the leading edge of the airplane's wing. This was not an entirely new idea, but, on previous airplanes, the slipstream of uncowled engines and propellers too near the wing interfered with the flow of air over the wing. With the addition of engine cowlings, engineers placed the engine further ahead of the leading edge of the wing. This not only prevented interference between the propeller and wing but also minimized the engine's drag.

Thus, by the early 1930s, the basic features of the streamlined cantilevered monoplane were available to airplane designers. Once the Monomail and Alpha had proven the advantages of stressed-skin all-metal construction, it was only a relatively short step between their efficiency and that of the DC–3. Other significant improvements would be the addition of more powerful twin engines mounted on the wing and the use of variable-pitch propellers and wing flaps.

Improved Propellers and Wings

In the early years of the airplane, wooden propellers were the only airscrews available to convert engine power into thrust. Most military aircraft in World War I used two-blade wooden propellers, but, occasionally, four-blades became necessary for more thrust. As long as the speed of the airplane did not exceed 80 miles per hour, propeller diameter and strength posed no problems for designers. As airspeed and engine power increased, however, wooden propellers presented a number of problems. By 1929, small racing planes had achieved speeds as high as 350 miles per hour. Engines operating at these speeds turned at the rate of 3,000 revolutions per minute, forcing a propeller 9 feet in diameter to move through the air at approximately 1,450 feet per second. This means that much of the propeller blade exceeded the velocity of sound (about 1,100 feet per second). The result was a loss of efficiency and a high level of noise in the cockpit. **Reduction gearing*** between the engine and the propeller in the late 1920s eliminated this problem.

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* A type of airplane construction in which the skin bears all or part of the stress arising in the airplane.

** A surface that smooths the flow of air at an internal angle, as at a wing root.

A little earlier, engineers found that metal propeller blades could be made thinner and, therefore, more efficient at high speeds than wooden blades without reducing their strength. The first successful metal propeller was the Reed propeller, named after its American inventor Sylvanus P. Reed. This was a two-blade propeller made of duralumin and twisted to the angle required by a given engine or airplane. Reed soon replaced the two-blade propeller with a three-blader made of the same material.

As the airplane increased its cruising speed in the 1920s, it became impossible for engineers to design a fixed-pitch propeller that would operate efficiently under all flight conditions. In other words, a propeller designed for maximum efficiency at cruising speed would not operate efficiently at takeoff. An airplane with a high cruising speed and a fixed-pitch propeller required too much space for its takeoff run. The need was a propeller that would operate at maximum efficiency during takeoff, climb, cruising speed, and top speed. Designers met this need by changing the pitch of the propeller blades to suit each operating condition. Propellers with this capability became known as variable-pitch propellers.

The first practical variable-pitch propellers were controlled manually by the pilot from the cockpit. For many years, the pilot had the choice of only two propeller variations—a fine pitch for takeoff and a course pitch for cruising. Eventually, engineers created hydraulic and electric controls that permitted more than two blade settings. This led to variable-pitch propellers of the constant-speed type. These propellers automatically change their rotational speed to match the speed of the engine under all flight conditions.

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* A gear assembly between a powered shaft and another shaft by which the latter shaft is driven at lower rpm than the powered shaft.

The first commercial airline to use variable-pitch propellers was the Boeing Company in 1932. Company engineers originally designed the 247 for fixed-pitch propellers, but they became dissatisfied with its takeoff performance from airports located in the Rocky Mountains. With variable-pitch propellers, they improved the airliner's efficiency in every phase of operation. Its normal takeoff run reduced by 20 percent; its rate of climb increased by 22 percent; and its cruising speed increased by 5½ percent. After this demonstration, no American aircraft designer, including the Douglas Company, attempted to build a high-performance airplane without variable-pitch propellers.

In addition to the improved efficiency brought by variable-pitch propellers to the airplane, significant innovations occurred in wing design during the twenties and thirties. Early in the airplane's development, designers searched for ways to reduce drag and increase speed. As they increased the machine's top speed, however, landing speed likewise increased. To hold landing speed at a safe level, British designers in 1916 created the first air brakes when they fitted the Sopwith biplane with flaps at the rear center section of the wing. These flaps hinged upward to brake the flow of air during landing. This was the first known application of wing flaps as braking mechanisms.

Although these early flaps served their purpose, the simplest and most effective flap is a section of the trailing edge of a wing hinged downward to increase lift rather than drag as the air brakes had done on the early Sopwith. The aileron used on the Farman biplane of the mid-1900s for lateral control is a direct forerunner of this type of flap. And the aileron evolved from the Wright brother's practice of wing warping.

The most significant development in the evolution of the wing flap came during the early 1920s with the invention of the slotted wing or flap. Patented in England by Handley Page Ltd, this device is a curved retractable slat that projects from the leading edge of the wing and opens a slot between it and the wing. Lowering the flap forces air through the slot and over the upper surface of the wing. This makes for a smooth flow of air over the wing and reduces turbulence during steep climbs. This innovation not only eliminated stall-and-spin crashes but also increased the airplane's speed.

A second type of flap widely used on the early streamlined monoplanes was the split flap. This flap is a hinged section of only the underside of the wing at the trailing edge. When this flap is lowered, it leaves the upper surface of the wing intact. It was quite useful on the thick wings of the early monoplanes because they needed increased drag and lift to steepen their gliding angle as they approached for landing. Another type of flap developed during the twenties was the Fowler, a flap that increased both the area and the camber of the wing. This flap is basically a small airfoil hinged on the trailing edge of the wing. As it extends backward and downward, it leaves a slot between it and the main wing. The net effect of this flap was to provide greater lift with an increased wing area.

Engineers first used flaps in the 1930s to overcome basic weaknesses in the design of their airplanes. The low drag of such early monoplanes as the Boeing Monomail, the Northrop Alpha, and the Lockheed Orion gave them a shallow gliding angle and made them difficult to land. The split flap provided increased drag for a steeper descent and increased lift to make them fly more slowly. Designers later adopted the slotted and the Fowler flaps when they realized that flaps permitted higher wing loadings and improved takeoff performance. Much of the airplane's increased efficiency during the 1930s came largely from the widespread use of flaps (Fig. 41).

Continuing interest in flaps in the late 1930s brought further improvements in the slotted flap with Handley Page patenting a method of enclosing its operating mechanism inside the wing. The Italian Piaggio Company developed a form of **double-slotted flap,** and, though not widely used at the time, its influence appeared later in the triple-slotted flap used on the modern Boeing 707 airliner. The type of double-slotted flap that gained wide acceptance featured two slots between the flap and the wing. The most important recent developments have been the use of **leading-edge flaps** on aircraft with swept-back wings and the triple-slotted flap.

Engine Development

Of all the improvements made in airplane design between World War I and World War II, the most far-reaching development was the creation of more powerful engines. Commercial airliners in particular probably would not have advanced beyond the efficiency of the Ford trimotor if more reliable and powerful engines had not been available. Reduced operating costs and the availability of more engine power for the same weight were directly responsible for the creation of the new metal monoplanes. One of the most serious handicaps faced by commercial airlines in the early twenties was the high cost of engine maintenance. Frequent engine overhauls at intervals of every 50 hours or

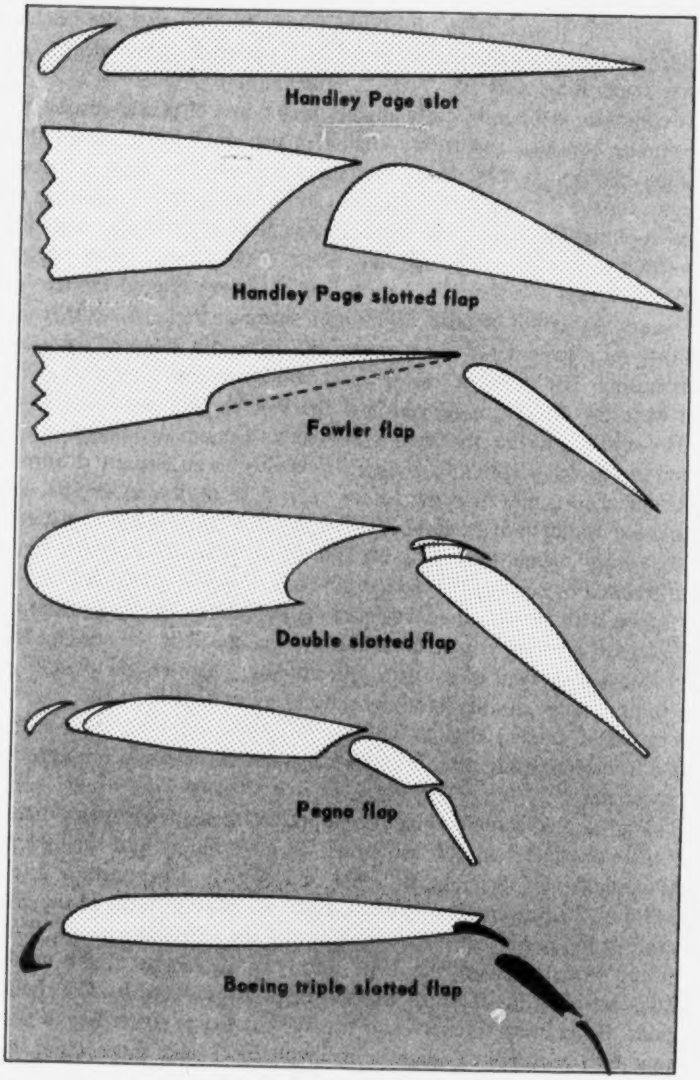
Handley Page slot
Handley Page slotted flap
Fowler flap
Double slotted flap
Pegna flap
Boeing triple slotted flap

Figure 41. Wing flaps were first used as braking mechanisms. The flaps shown above came into use to increase lift, eliminate stalls, and improve takeoff performance.

so made the civil airline business a risky undertaking. Even after wartime emphasis shifted from air-cooled rotary engines to water-cooled engines, engine maintenance took almost 50 percent of the airline industry's operating costs.

A common problem of early engines was a loss of power caused by inadequate cooling. The rotary engine in use until 1914 solved this problem. Although this engine was more complicated than previous designs, it gave the low-speed airplanes of that period the advantage of extra cooling. The rotary engine could not meet wartime demands for more power, however. The spinning effect created by a **rotary engine** made the airplane difficult to handle and therefore limited the size of the rotary that could be used. Aluminum water-cooled engines met the military requirement for more power, but they still required frequent overhauling. The most successful water-cooled engines used during the war were the American *Liberty* and the French *Hispano-Suiza* V–8.

The solution to the problem of engines was the development of the radial air-cooled engine. This engine operates on an entirely different mechanical principle than the rotary engine. In the **radial engine,** the crankcase and cylinders remain stationary, and the crankshaft rotates. In the rotary engine, the crankcase and cylinders rotate around a fixed crankshaft. For cooling, the radial air-cooled engine relies entirely on the speed with which air moves past its cylinders. Although rotating cylinders in a rotary engine contribute to the speed of the cooling air, they lose a great deal of power in the process. These characteristics of the rotary engine and its handling difficulties caused it to give way to the radial air-cooled engine. Today, all large air-cooled engines are radial in design, quite often with two rows of cylinders in a staggered arrangement.

The air-cooled radial engine developed in the United States primarily under the leadership of two firms—Pratt-Whitney and the Wright Aeronautical Corporation. In 1924, the Wright Corporation introduced the 220-horsepower seven-cylinder *Whirlwind*. Most of the civil aircraft of the period used this engine until the 400-horsepower Pratt-Whitney *Wasp* replaced it in 1927. Many of the famous flights of the 1920s, including the flight of Lindbergh, were powered by *Whirlwind* engines. Both Pratt-Whitney and the Wright Corporation began producing 500-horsepower engines in later 1927 and gave them the names *Hornet* and *Cyclone*. This began a long period of competition with the names *Wasp* and *Cyclone* becoming household words in aviation to designate air-cooled radial engines of rapidly increasing power. The period from the early thirties to the outbreak of World War II saw the steady advance of both air-cooled and liquid-cooled engines to power levels as high as 1,500 horsepower—almost a threefold increase since the end of World War I. Still further progress came during the early years of World War II when the piston engines developed power outputs well over 3,000 horsepower.

Improved Fuels

A striking feature of the technical advances during the 20-year period before World War II was that engineers obtained more power from engines without increasing their weight. This was possible partially because of higher quality fuels that permitted higher **compression ratios*** and supercharger pressures. Fuels available for airplanes of the 1920s had **octane ratings**** of about 50 and were little better than automobile fuels. Since engines could be run only with low compression ratios, air-cooled engines could not increase their power beyond a certain level without knocking.

Shortly after World War I, scientists in America and Great Britain discovered that some gasolines have higher anti-knock qualities than others. Further experiments led to the addition of **tetraethyl lead,***** which gave fuels an octane rating of 80 to 87. This sudden improvement in the quality of fuel resulted both in more engine power and less fuel consumption. Better fuels in large measure made possible the development of the DC–2. By using the twin-engine design, engineers were able to build an airplane as large as the DC–2 and obtain as much power from two engines as they had previously provided from three. Fuel continued to improve throughout the thirties and reached a standard octane rating of 90. Today, the octane rating of aircraft fuel ranges from 115 to 145.

Other Refinements

Both airplanes and ships present navigational problems completely different from any other mode of transportation. But the navigation of an airplane is even more unique than that of a ship. In the first place, an airplane has freedom of vertical movement which means that it has the capability of not only moving forward but of flying at low or high altitudes. This makes it necessary for a pilot to know exactly how high he flies, particularly over mountainous terrain. A second feature of the airplane is that it travels at much higher speeds than ships and other surface transportation media. Thus, in addition to his altitude, a pilot must always know his location and the actions necessary to keep him on course.

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* The ratio of the volume of a gaseous mixture in an engine cylinder at the beginning of the compression stroke to its volume at the end of the stroke.

** The rating of a liquid fuel indicated by its octane number.

*** A liquid $Pb\ (C_2H_5)_4$, used as an anti-knock in gasoline.

Modern instrument systems provide such information when a pilot is within range of a well-equipped airport. Many aids give a pilot his location at the moment he makes an observation, but, if he happens to be off-course at the time, he may drift further off by the time he takes corrective action. For many years, pilots on long flights depended on a rather simple method called dead reckoning as a navigational aid. This method consists of computing the position of an aircraft on the basis of airspeed, elapsed time since departure, wind speed and direction, and compass heading. On every flight, the pilot follows a flight plan which specifies his speed, course, and altitude. If he has reliable instruments to follow this plan and if weather conditions are as forecast, he has little if any navigation problem. But flight plans must often be changed for one reason or another. A pilot then must be able to make corrections in his course if he expects to reach his destination.

In the early days of the airplane, pilots made only short, slow flights at low altitudes over familiar territory. As civil flying gained in popularity after World War I, pilots first depended on specially prepared maps and then on elaborate systems of airfields and land markings. Obviously, these systems are practical only when they can be seen from the air. The airmail pilots who flew the "graveyard runs" over the Allegheny Mountains during cloudy or foggy weather often complained of "cockpit vertigo." They tended to lose all sense of direction in heavy clouds and could not tell whether they were flying up or down. A pilot might think he was climbing upward out of a cloud and then moments later discover that he was plunging toward the ground. Blind flying was one of the most dreaded hazards of these early flights.

Engineers solved this problem by adding three basic instruments to the airplane's instrument panel which previously consisted only of a gasoline and oil gauge. About 10 years after World War I, a young Army Air Corps Lieutenant, James Doolittle, first tested these instruments on a blind flight of 16 miles. After becoming airborne, he guided his plane in an almost perfect circle around the landing field. A directional gyroscope indicated the degree to which he was banking, skidding, or rolling away from his circle. An altimeter showed even the smallest change in his altitude. As he prepared to land, he carefully observed another revolutionary instrument that became known as the "artificial horizon." On the face of this instrument was a bar that kept him oriented to the real horizon regardless of his plane's movement. This instrument told him whether he was flying above or below the horizon. As he landed, the sound of a third instrument told him whether he was approaching the ground at the proper angle. He was following a radio beam transmitted to his airplane by a ground station. Every passenger airliner was equipped with these basic instruments in the early 1930s.

In addition to these and certain other sensitive engine instruments, the period saw such additions to the pilot's dashboard as an airspeed indicator, a rate-of-climb indicator, a bank-and-turn indicator, and de-icing control. One of the most important advances of the period was the introduction of the automatic pilot. The original purpose of the automatic pilot was to reduce pilot fatigue on long flights. It later became an important navigational aid to provide information on an aircraft's position. The first such instrument was used on a Curtiss seaplane in 1912 and included a single directional gyroscope. Later airplanes added three gyroscopes to prevent pitch, roll, and yaw during a prescribed flight course.

Originally, a magnetic compass controlled the automatic pilot and held it on a fixed course set by the human pilot. If the pilot found it necessary to change his course, he had to reset the autopilot mechanism. With this mechanism in the late thirties and forties, a pilot could fly for one hour at a speed of 250 miles per hour and not deviate more than 10 miles from his original course. Later, with the addition of a repeating compass, the pilot could determine his longitude and latitude and hold to an even more accurate course. The introduction of modern radar methods for direction finding and range enabled the pilot to feed up-to-the-minute information into the automatic pilot to maintain his desired course. The next momentous step in navigational accuracy incorporated the principle of the automatic pilot into a complete system known as inertial navigation. This system enables the pilot to set his course at the beginning of a flight. After he is airborne, an automatic dead reckoning system calculates the flight path and corrects deviations by making appropriate adjustments in the aircraft's controls.

The research of the 1930s yielded other equally important innovations in the design and structure of the airplane. One important development was the pressurized cabin which, together with improved engines and fuels, enabled the airplane to fly higher and faster. Engineers had known for some time that the reduced density of the air at high altitudes permits the airplane to fly faster and therefore more efficiently than at sea level. For example, an airplane generating the same power can fly 38 percent faster at 30,000 feet than it can at sea level. The increase is 17 percent at 20,000 feet, the altitude at which most piston-engine commercial airliners fly.

The Boeing 307 was the first passenger airliner to feature a system of regulating pressure inside the cabin. Most airliners today still use much the same system as that developed by Boeing, even though later systems were designed to reduce the rate at which air pressure changes as the airplane climbs or descends. The original Boeing system included two compressors driven by the airplane's engines. An inlet valve controlled a constant rate of outside air fed into the cabin by the compressors. The outflow of air was regulated by two pairs of valves that controlled internal pressure. This system maintained cabin pressure that equalled the pressure of an altitude of 8,000 feet and prevented a difference in pressure between the air in the cabin and the outside air from exceeding 2½ pounds per square inch. On a modern jet airliner, the difference between the air pressure inside the cabin and the outside air is 8½ to 9 pounds per square inch, the equivalent of 6,500 feet altitude inside the cabin when the airplane flies at 40,000 feet. Supersonic airliners flying at 60,000 to 70,000 feet will require even greater differences in air pressure.

Another major change in airplane design came in the late 1930s with the addition of a tricycle undercarriage that retracted into the wings. Although this development did not directly improve the airplane's efficiency, it made landing and taking off more comfortable for passengers. It also made it possible to reduce the length of runways since aircraft with tricycle undercarriages can be braked more severely without nosing over.

The DC–3—A Biography

The Douglas DC–3, the most famous airliner ever built, made its first commercial flight in July 1936 from Chicago to New York and saw continuous service throughout the world for almost 30 years. Beginning with its first flight, it rapidly became the model for all other airliners, even the jumbo jets of today. During World War II, it operated under such military names as SKYTRAIN (C–47), SKYTROOPER (C–52), and DAKOTA. The Allies used it extensively throughout the war as a transport plane to move cargo, personnel, and paratroops, as a glider tug, and as an airborne ambulance. Following the war, it served in the famous Berlin Airlift and in vital cargo missions that carried it from the Arctic to remote jungles in Africa and Asia. Popularly known as the "Gooney Bird" by military pilots and as "The Model-T of Aviation" by the commercial airlines, this airplane performed in its day with unmatched reliability. It was the ultimate in air transportation.

The DC–3 had its beginning as a transcontinental sleeper transport but rapidly developed into an all-purpose airliner that incorporated the latest innovations in aircraft design. Donald Douglas, the president of the Douglas Aircraft Corporation, described the new plane in these words:

> In the new design we actually had three airplanes. Initially, it started out to be a sleeper, the first airplane specifically designed as an aerial Pullman. But during the mock-up stages, it became apparent that the larger fuselage, increased wing area and the more powerful engines available made the basic design a very flexible airplane.

The company sales brochure introduced it to the traveling public as an unmatched experience in luxury:

> THE DC–3, 21-PASSENGER DAY PLANE—wider, longer and higher than the famous DC–2, with 21 lounge seats provided in the cabin in two rows; double seats on one side of the aisle and a row of single seats on the other.
>
> THE DC–3, 14-PASSENGER SKY CLUB—offering luxury and comfort of railroad club car appointments, being equipped with 14 deeply upholstered swivel chairs.
>
> THE DC–3 CUSTOM MODEL—living room or parlor furnishing in a roomy cabin; and "office aloft" for the traveling executive.

The DC–3 resembled its predecessor, the DC–2, but featured a larger wing area, span, and length, and greatly improved engines. It was powered by two 850-horsepower radial air-cooled and supercharged *Cyclone* or *Wasp* engines. Its cruising speed was 190 miles per hour at 11,200 feet for an average range of about 1,400 miles. It carried amost 3,000 pounds more payload than the DC–2 or any other airliner and weighed 24,000 pounds when fully loaded. Because of its size and design, engineers were able to take advantage of the latest technical advances—all metal monocoque construction, retractable landing gear, engines mounted on the wings, variable-pitch propellers, wing flaps, supercharger, and cockpit instruments that permitted all-weather and night flying (Fig. 42).

More than any other airplane, the DC–3 converted millions of land lubbers to the idea that air travel is a safe and practical medium of

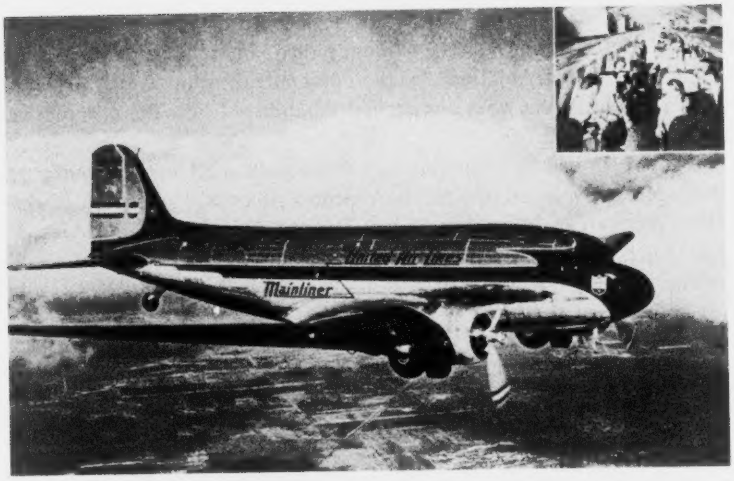


Figure 42. Modern jet planes travel farther, carry more passengers, provide more comfort, and fly higher, but, in the progress of modern commercial air travel, the DC–3 is a major milestone.

transportation. It was the first flying machine to put air travel on a common carrier basis. Not only did it reduce operating costs with its design, construction, and performance. It brought the traveling public a fast, safe, and reliable transportation service. On the day that TWA initiated DC–3 service in Dayton, Ohio, Orville Wright, the Father of Aviation, inspected the shiny new airplane and commented with a twinkle in his eye:

> The body is big enough to carry a sizable payload and that is important. There is plenty of room and the seats are comfortable. They tell me, too, that it is so sound-proof that the passengers can talk to each other without shouting. . . . Noise is something that we always knew would have to be eliminated in order to get people to fly. . . .
>
> The airplane should be used to bring all the peoples of the world closer together. Development of an airliner such as this is a big step in the right direction. The big thing that will bring this about is safety. I think they've built everything possible into this machine to make it a safe and stable vehicle of the air.

Douglas officials estimate that DC–3 airliners logged more than 80 million flying hours, while carrying 500 million passengers approximately 100 billion passenger miles.

One of the DC–3's most attractive features for the airline industry was the greatly reduced cost of maintenance. With the exception of fabric-covered rudder, ailerons, and elevators, its all-metal construction was easy to repair and keep clean. Repairmen could work on control cables and other internal parts through flap covers in the wing and fuselage without a major disassembly. A new engine mount with fuel lines and electrical connections plugged into permanent fittings like an electric plug in a wall socket. This enabled mechanics to change engines in a maximum time of two hours. Little or no effort was required to remove a wing panel and bolt a new one in place. The result was a drastic reduction in the cost of maintaining the airplane. Even more important, the airlines could keep their planes in the air without long expensive delays for maintenance. For the first time, the airline industry could report profits made solely from hauling passengers.

As outstanding as were the DC–3's achievements as a commercial airliner, its war record was even more spectacular. When the Allies invaded Normandy on D-Day, 6 June 1944, Gooney Birds filled the skies in support of the invading armies. Charles Collingswood, a news reporter on the scene, described the action by radio:

> The sky is darkened with swarms of cargo planes, and the roar of their motors is like the thunder of the war gods. The steady stream of transports keeps coming and coming and coming in an endless train. The awe of the thing actually has stopped gunfire in some sectors. . . . Men look skyward with unbelieving eyes.

Some planes with stripped-down interiors and special attachments on their fuselages carried jeeps, small cannon, ammunition, and spare parts for tanks. Others were towplanes, pulling gliders filled with troops. During the first 50 hours of fighting, DC–3s carried more than 20,000 paratroopers and their weapons from England across the English Channel to the Normandy beaches. In this greatest airlift of all times, more than 1,000 DC–3s carried gross weights far beyond their rated capacity and performed unbelievable feats.

Before the war ended, tales of the DC–3's amazing performance came from the far corners of the earth and sounded more and more like some of the Paul Bunyan legends. Douglas engineers filled company files with the Gooney Bird's accomplishments, but even they found some of the stories so fantastic that they could not believe them. They often could only shake their heads and say, "Impossible! No airplane could have done that, not even ours."

One story was told of Plane No. 4823, a DC–3, that had become a member of the Royal Australian Air Force. One day it was flying across the Owen Stanley Mountains in New Guinea toward Australia when it hit a tropical thunderhead at 12,000 feet. The turbulence flipped the plane on its back, and, from this position, it began plunging toward the jungle in a high-speed loop-the-loop dive. At 4,000 feet, the pilot finally managed to pull it out of the dive, but not before its 26 passengers and cargo of 6,000 pounds had been churned about inside like so many leaves in the wind. When the plane landed at an Australian base, a Douglas engineer wrote this report:

> I found wrinkles in the wing running from the leading edge aft and outboard across the entire length of both wings. The stabilizer was wrinkled in the same fashion. Rivets had been torn away as far back as a foot from the leading edge. One rib was hanging by a single rivet.
>
> The pilot inquired if it was safe to fly the airplane some 600 miles over water to his original destination. Naturally, I advised against it. Disregarding the advice, he had the cargo removed and took off anyway.

He made the trip without incident.

Another DC–3 made a forced landing in an Asiatic jungle. During repairs, a flight of Japanese Zeroes riddled the fuselage and blasted one wing off. There were no spare DC–3 wings available. The crew substituted an old DC–2 wing that was 10 feet shorter and not designed to carry the load of a DC–3. They grafted the wing on the DC–3 and flew the hybrid plane to its home base. It became known afterward as the DC–2½.

Even after the war ended and other more modern airliners took to the skies, passengers often chose the DC–3 over faster planes. One passenger commented that jet travel was wonderful, but, in a DC–3, he felt that he was really flying. He explained his preference in these words:

> It means, usually, we fly at lower altitudes and I like to see the countryside. Any other way is too fast. Moreover, I like the sensation of flying which you get in a DC–3 and don't usually get in the bigger planes. Somehow, you feel like you're a part of this airplane. The others are cold and indifferent; they don't have any personality. Me? I guess you'd say I'm a DC–3 buff!

One of the most outstanding characteristics of the DC–3 was its exceptional durability. It was designed, of course, when knowledge of aeronautical engineering was still limited. As a result, early engineers over-designed it in many respects. They used stronger materials at many points than were necessary and applied methods appropriate to more advanced airplanes. Even to this day, there are few planes in the sky that feature the combination of outstanding characteristics as those of the DC–3.

SUMMARY

With the addition of a more powerful engine, cantilevered wing, and other innovations, the airplane developed into an effective weapon of war. Large multiengine bombers were the most significant developments during the war years. It was only a short step between these bombers and the flights of the first commercial air transports.

Although aviation made outstanding progress during its first 20 years, the most spectacular advancements came during the 25 years following World War I. In the immediate postwar years, public and private interest in aviation faltered while the world adjusted to peacetime conditions. Interest in flying soon revived, however, as daredevil pilots flew from city to city demonstrating their skills and the efficiency of their machines. Other flyers, eager to restore public confidence in the airplane, made record-breaking flights across oceans and continents.

Commercial air transportation began in Germany three months after the war with intercity flights between Berlin, Leipzig, and Weimar. Commercial flying in the United States began with the airmail operations of the US Post Office in 1918. The first Government recognition of commercial aviation was the passage of the Kelly Act in 1925, authorizing the Postmaster General to contract for airmail service. The Government provided further incentives to commercial aviation in 1926 and 1930 with the Air Commerce Act and the McNary-Watres Act. This legislation and Lindbergh's famous flight led to the creation of as many as 44 different commercial airlines by 1929. Many of these companies later merged into transcontinental systems with such familiar names as Transcontinental and Western Air (TWA), United Airlines, and American Airways.

By 1930, people were flying coast to coast in 48 hours at an average cost of $351.94. Three years later, the Boeing Aircraft Company introduced the world's first modern airliner, the Boeing 247, an all-metal monoplane that carried passengers at speeds up to 170 miles per hour. Quickly on the heels of this development came even more modern airliners—the DC–2 and the DC–3. The DC–3 became the world's most famous airliner and military transport. It carried 21 passengers in almost total comfort, climbed to an altitude of 20,000 feet, and covered a distance of 2,000 miles at 200 miles per hour. This aircraft captured 90 percent of the commercial market just prior to World War II.

The major problem facing the airline industry throughout the twenties and thirties was the high cost of operation. In the early stages of the airplane, designers concerned themselves primarily with the creation of an airworthy and controllable machine. Only after a commercial market developed did the efficiency of the airplane become a primary concern. The search for efficiency led designers to consider methods of reducing drag, improving engine power, and increasing speed. This search led to streamlining, which brought radical changes in the shape of the airplane. These changes included the high-wing, all-metal monoplane, engine cowlings, retractable undercarriages, and engines mounted on the leading edge of the wing.

Another major change was the shift from wooden propellers to three-blade metal propellers. Then came the need for a propeller that would operate at maximum efficiency under all flight conditions during takeoff, climbing, and cruising. Designers created the variable-pitch propeller, which could be adjusted to meet each operating condition. At first, the pilot could make only two propeller variations. Engineers then created hydraulic and electric controls and constant-speed propellers that automatically maintained their RPM (revolutions per minute) as engine speed changed.

A number of other features increased the overall efficiency of the airplane and, at the same time, made it a much safer transportation medium. The addition of flaps, for example, not only increased airspeed but also brought improved performance in taking off and landing. One of the most far-reaching developments was the creation of more powerful engines. For years, designers had struggled with engines that either generated insufficient power or overheated at high speeds. This problem ended with the development of the radial air-cooled engine. A striking feature of radial engines was that they provided more power without increasing their weight primarily because tetraethyl lead had improved the quality of engine fuels. Other innovations included vastly improved equipment, such as the artificial horizon, the altimeter, automatic pilot, and pressurized cabins.

The most famous airliner ever built, the DC–3, incorporated most of the latest innovations in design and performance. These advances included an all-metal monocoque construction, retractable landing gear, engines mounted on the wings, variable-pitch propellers, wing flaps, supercharger, and improved navigational instruments. Among its outstanding features were its exceptional durability and reduced cost of maintenance. It not only put air travel on a common carrier basis; it provided the public with a fast, safe, and reliable transportation service.

WORDS AND PHRASES TO REMEMBER

Air Commerce Act
Civil Aeronautics Act of 1939
compression ratios
cowled
drag
double-slotted flap
Fowler
Kelly Act
leading edge flaps
McNary-Watres Act
octane rating
pressure differential
radial engine
reduction gearing
rotary engine
scheduled airlines
slotted wing
split flap
stressed skin metal structures
tetraethyl lead
transcontinental
triple slotted flap
variable-pitch propeller
wing fillet or fairing

NAMES TO REMEMBER

Alcock, John
Byrd, Richard
Goddard, Robert
Hawker, Harry
Kelly, Oakley
Lindbergh, Charles
Macready, John
Maughan, Russell
McKenzie-Grieve, Kenneth
National Advisory Committee for Aeronautics (NACA)
Spirit of St. Louis
Townend, H. L.
Whitten-Brown, Arthur
Whittle, Frank

QUESTIONS

1. **Discuss the most noteworthy changes in the appearance of the airplane by the end of World War I.**
2. **Why did the JN-4 Curtiss "Jenny" become the most popular airplane in the immediate postwar period?**
3. **Discuss barnstorming and its effect on postwar aviation.**
4. **Describe some of the most famous long-distance flights following World War I. How did these flights convince the public that the airplane had become an accepted mode of transportation?**
5. **How did scheduled airmail service get started in the United States? What effect did the airmail service have on the growth of commercial airlines in the United States?**
6. **In what four ways did Congress encourage the growth of commercial aviation in the period between World War I and World War II? What**

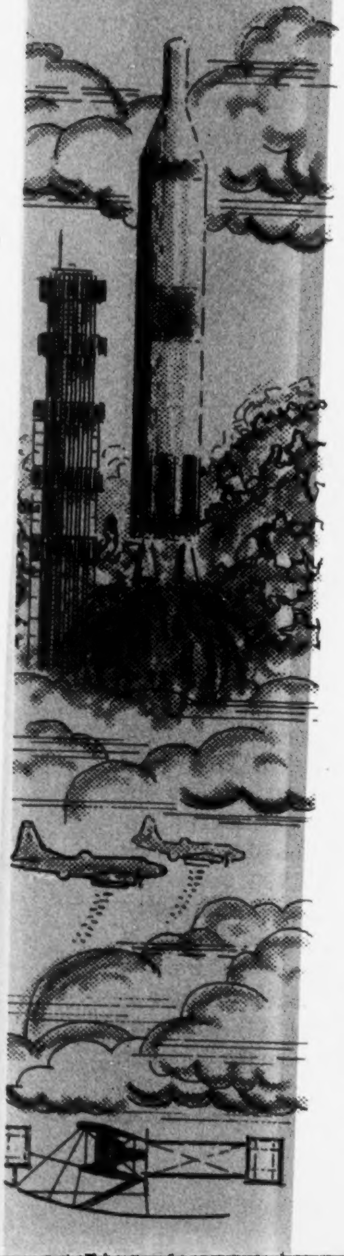
was the effect of competition between rival airline companies on the growth of commercial aviation?

7. **What airplane had the distinction of being the first commercial airliner built in the United States? What is the significance of the Boeing 247, the DC-2, and the DC-3 in commercial aviation?**
8. **What aerodynamic improvements gave the DC aircraft an initial economic advantage over other commercial aircraft?**
9. **How did the search for efficiency lead to major innovations in aircraft design?**
10. **How did the application of streamlining produce major changes in the shape of the airplane?**
11. **What effect did increased speed have on the airplane's wings and propellers?**
12. **How did aircraft designers finally resolve the problem of engine power?**
13. **How does the navigation of an airplane differ from that of other transportation media like the automobile and the steamship?**
14. **Discuss the major changes that occurred in the pilot's dashboard in the period of the thirties and forties.**
15. **What characteristics made the Douglas DC-3 the most famous airliner ever built? What special features made it attractive both to the airline industry and the traveling public? Give some examples of the DC-3's performance.**

THINGS TO DO

1. Read and report to the class on some famous pioneer flights made during the 1920s and 1930s. Construct maps showing the routes taken by these early flights.
2. Trace the routes of the first transcontinental mail service on a map of the United States.
3. Collect pictures for your scrapbook, showing some of the changes that occurred in airplane design during the period of the 1920s and 1930s.

Chapter 5



The Aerospace Threshold

THIS CHAPTER describes the advent of practical jet propulsion and rocketry and their impact on military and commercial aviation. Also included is a discussion of the airplane's role in World War II and further significant changes brought by the war on the evolution of flight vehicles. First, the chapter describes early experiments in jet propulsion and rocketry in Great Britain, Germany, and the United States. Next, it discusses some of the outstanding military aircraft, pilotless missiles, and long-range rockets that became operational during World War II. It describes the evolution of the practical helicopter and the influence of military aviation on the development of commercial air transportation. When you have studied this chapter, you should be able to do the following: (1) describe the experiments that led to the creation of the jet engine, rocketry, and guided missiles; (2) identify and describe some of the outstanding military aircraft of World War II and the technological improvements which they brought to aviation; (3) describe the impact of guided missiles and jet aircraft on the conduct of war; (4) trace the evolution of the helicopter, citing the contributions of Leonardo da Vinci, Juan de la Cierva, and Sikorsky; and (5) describe some of the outstanding four-engine airliners to emerge from World War II.

THE AIRPLANE made rapid and revolutionary advances during the period of the twenties and thirties. But further momentous developments were to come with the application of jet propulsion and rocketry to the flying machine.

Man had known and used the principle of jet propulsion for centuries before he applied it to the airplane. As early as 400 B. C., Archytas of Tarentum amazed his friends with a flying wooden pigeon. He suspended the pigeon in the air with wires and propelled

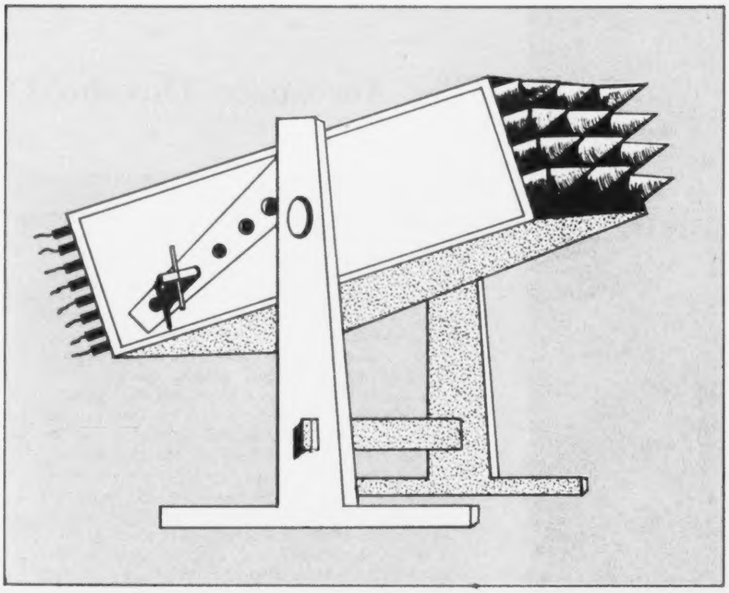


Figure 43. The Chinese probably invented rockets similar to those shown above and used them in battles from Baghdad to Japan during the thirteenth century.

it with some form of steam reaction system. Some 300 years later, Hero of Alexandria designed an aeolipile, which was a sphere mounted atop a steam kettle. Steam passed through a system of pipes into the sphere and escaped through nozzles on each side of the sphere. The force of steam through the nozzles gave the sphere a rotary motion. Unknown to Hero, this experiment demonstrated the basic reaction principle underlying both the jet and the rocket. In another part of the world, the Chinese used the jet principle when they burned powder to create high-speed gases for propulsion. It was not until the 1920s and 1930s, however, that jet propulsion became a practical reality for airplanes.

Historians generally agree that China introduced a primitive form of rocket in the eleventh century A.D. with the creation of an "arrow of flying fire." The first use of rockets in warfare probably occurred in 1232 A.D. during the Chinese-Mongolian wars (Fig. 43). There are numerous reports of rocket experiments in Europe from the thirteenth to the fifteenth centuries. In England, Roger Bacon experimented with gunpowder and rockets; a Frenchman by the name of Lehan Freissart hit upon the bazooka idea almost a half century before Christopher Columbus was born; and an Italian designed a rocket-propelled torpedo to destroy sea-going vessels. And, in the early nineteenth century, Francis Scott Key recorded the use of rockets in the "Star Spangled Banner," after watching British warships bombard Fort McHenry in the War of 1812. But it was the achievements of Frank Whittle, Robert Goddard, Hans Ohain, Hermann Oberth, and others that brought man to the threshold of jet and space travel.

JET PROPULSION AND ROCKETRY

Two events forecast the ultimate decline of the airplane as a weapon of war and its further rapid development as a transportation medium. One announced its arrival with a strange piercing sound like the screams of 10,000 banshees. The man who produced the sound in England described it as a "terrifying crescendo of noise" with a "rising shriek like an air raid siren." In Germany, another experimenter called the sound a "hideous wail" and a "remarkable howling and whistling noise which made the whole workshop shudder." So shattering was the noise to employees at the British Thomson-Houston plant that company officials ordered the removal of the apparatus. The German experimenter built a separate shed outside the main plant and directed the noise and flaming exhausts over a lonely river. Both men during 1937, each unknown to the other, were bringing a new, unparalleled source of power into the world. The noise was the birth cry of jet propulsion.

Auburn, Massachusetts, was the scene of a somewhat different, yet similar, event in 1926 as four people prepared to launch the world's first liquid-propellant system. A rocket approximately 10 feet long stood almost vertically on a simple launcher, and a small alcohol stove stood beneath the rocket. One of the people was the launch director, another was the igniter, and a third, the photographer. There was no countdown, no television audience, and no far-flung tracking stations. With a nod to his igniter, the launch director opened the fuel valves, and the igniter applied the necessary heat. The rocket blasted off the launcher with a loud roar, sped through the air for 2½ minutes, and then dropped to the ground. It had traveled 200 feet at a speed of about 60 miles per hour.

In their own way, both the wail of the **jet engines** and the roar of the rocket were as significant as the first flight of the Wright brothers. Little did the world realize that, in only a short time, men would fly in jet airplanes at more than twice the speed of the DC–3. And quickly on the heels of this achievement, other men would sit astride a giant rocket and speed through space to the moon.

Jet Propulsion and its Implications

Both jet and rocket engines apply Sir Isaac Newton's third law of motion—every action produces an equal and opposite reaction. The action in both engines is the expulsion of high-speed jets of gas to the rear. The reaction is a push in the opposite or forward direction. The major difference between the jet and the rocket is that the jet is an air-breathing system which draws air from the atmosphere and uses it to burn fuel. This, in turn, creates propulsive gas. The rocket also uses oxygen to burn fuel, but it carries its own oxidizer, or air substitute, to support propulsive combustion.

One of the first men to point in the direction of a modern turbojet engine was Sanford A. Moss, a graduate student at Cornell University in 1900. He wrote a thesis for his master's degree on the subject of turbine machinery and, in 1902, disturbed the academic repose of the Cornell campus with a fire-spurting gas turbine. Without heat-resisting metal, this turbine was not practical for everyday use, but Moss had shown others a way to build high-speed rotating turbines.

In 1928, **Frank Whittle,** a young cadet in the Royal Air Force (RAF) college, wrote a paper entitled, "Future Developments in Aircraft Design." With diagrams and figures, he suggested that a **gas turbine** was the logical means of propelling airplanes at high-altitude speeds above 500 miles per hour. RAF fighter planes driven by piston engines at the time made top speeds of only 150 miles per hour. Believing that **piston engines*** would not meet the needs of planes flying over this speed, he produced an experimental propulsive jet with a fan driven by a piston engine. The British Air Ministry studied the idea and concluded that it was impractical "because materials did not exist capable of withstanding the combination of high stresses and high temperatures."

Undismayed, Whittle filed a patent on his idea in 1930 but received no encouragement from the governments of either Great Britain or the United States. Time passed; the patent lapsed; and, in 1935, a newly formed company called Power Jets, Limited, agreed to Whittle's proposal for an airplane powered with a gas turbine engine. The RAF granted Whittle a release from active duty for one year of postgraduate research, and he began immediately to develop an experimental gas turbine.

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* A reciprocating engine, esp., an internal combustion reciprocating engine.

Meanwhile, in Germany during the same year, a German industrialist, **Ernst Heinkel,** had also concluded that 500 miles per hour was the practical limit of piston-engine aircraft. A young rocket enthusiast named **Wernher von Braun** had approached him earlier with a proposal for pushing an airplane forward with a liquid rocket engine in the tail assembly. Von Braun had already developed the engine, but he needed a fuselage for bench tests. Heinkel assigned some of his employees to Von Braun's project and provided him with the fuselage of an HE–112 fighter plane that would become the HE–176 rocket plane. A fearless test pilot named Erich Warsitz agreed to join Von Braun in his fantastic experiment which, in the beginning, had no more official support than Whittle's project.

Soon after Von Braun got under way with his fiery experiment, Heinkel met a young assistant at the University of Gottingen, Hans von Ohain, who had done some preliminary research on turbojet propulsion. Heinkel built a small shed some distance from his main plant and also assigned some of his employees to help Ohain set up his machine. He thus underwrote two lines of propulsive research that would later bring Germany to the forefront in propulsion technology—Von Braun's development of liquid fuel rockets at Peenemunde and Ohain's creation of the first jet fighter, the Heinkel (HE) 178.

In England, Whittle heard vague rumors of these developments in Germany and worked feverishly to complete his gas turbine engine. By April 1937, he had obtained heat-resistant steel that he could use and prepared for his first bench test. Not knowing how the engine would perform, Whittle shielded himself behind a steel plate, while his workmen scurried for shelter in other parts of the plant. He opened the control valves, and, from the engine, there rose a whining shriek mingled with a deafening roar as a cascade of flames shot from the exhaust. As the crescendo increased, red-hot patches appeared on the combustion chamber, and Whittle realized that his engine was out of control. He searched frantically for some means to bring it under control and found that his fuel system was feeding too much kerosene to the burner.

This event had so terrorized other employees that Whittle moved his machine to a deserted foundry in a small town nearby. After numerous financial problems and a great deal of frustrating research, Whittle finally completed his engine and contracted with the Gloster Aircraft

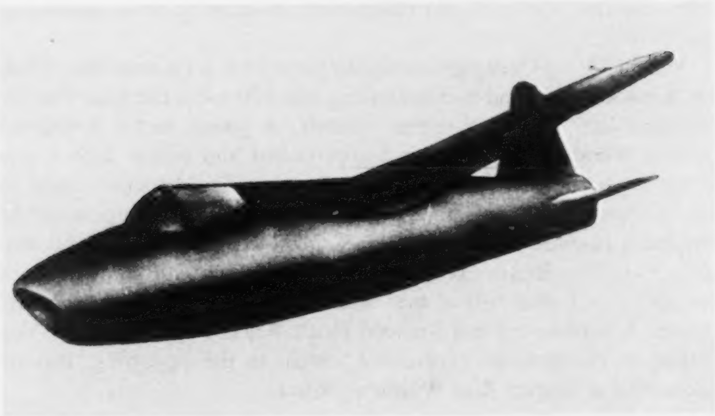

Figure 44. The first jet plane to take to the air was Hans von Ohain's Heinkel HE–178 with a centrifugal-flow turbojet engine.

Company for a specially designed airframe. The result was a combination of engine and airplane in 1941 called the Gloster-Whittle E–29/39, one of two airplanes that flew with practical jet propulsion systems in the early stages of World War II.

Although Von Braun proved in 1937 that winged flight was possible without a propeller, his interest shifted to liquid-fuel rockets after the West Peenemunde Rocket Experimental Station was established. Nevertheless, other scientists continued to test the HE–176 rocket plane and, on 3 July 1939, gave a demonstration before Adolph Hitler and the German High Command. Hitler stood impassively as the rocket plane took to the air with flames spurting from its tail, but he offered no visible support.

Hans von Ohain continued to experiment independently with his turbojet project and conducted his first bench test in September 1937, five months later than Whittle's first test. Heinkel designed a special plane in 1939 to carry Ohain's engine. The HE–178 had a wing span of 24 feet (Fig. 44). In the place of a propeller, it had a huge opening in the nose which funneled air beneath the cockpit into the combustion chamber. As the HE–178 soared into the air on the morning of 27 August 1939, the German High Command viewed the flight of the world's first jet-propelled fighter plane with cold indifference. As it turned out, they were preoccupied with another momentous event. German troops supported by the Luftwaffe invaded Poland five days later on 1 September. Fortunately for the Allies, this preoccupation continued until the latter stages of World War II. Toward the end of the war, Hitler sent German jet fighters against Allied bombers and took a heavy toll. These jets flew 50 miles per hour faster than the best Allied piston-engine fighters and 100 miles per hour faster than their bombers. However, the war ended before Germany could produce jet aircraft in large quantities.

Thus, it was the military that set the stage for the next major change in the design of the airplane. Experimentation at the hands of a few so-called civilian adventurers brought the airplane into being, but the expediencies of war and the need for more power were about to make it the world's fastest transportation medium. It would be more than 10 years, however, before the first jet airliner would make a scheduled flight.

Rocket Development

Most historians agree that the modern era of rocketry began in 1898 with the work of a Russian mathematician, **Eduardovitch Tsiolkovsky,** who conceived of space excursions in a publication entitled, "Exploration of Space by Rocket Devices." He developed a number of theories based on mathematical and chemical equations, suggesting that **liquid propellants** could be used in rockets to achieve the range necessary for spaceflight. His theory was that the speed and range of a rocket are limited only by its exhaust velocity and the amount of propellant that it can carry. He realized that a single rocket could not develop enough thrust to reach space and suggested the creation of step or **multistage rocket systems.** He also proposed space stations to launch probes into distant parts of the universe.

Modern scientists recognize Tsiolkovsky as the father of rocket theory, but it was an American, **Robert H. Goddard,** who became known as the father of practical rocketry. He became the first modern space pioneer in his study of solid and liquid propellants. Goddard began his work in rocketry in 1914 when he conducted a number of experiments with **solid-fuel propellants.** By 1916, he had received patents on his solid-fuel rocket motor and the multistage rocket. He then proposed to use his multistage rocket to boost weather balloons far beyond their limit of 20 miles. Goddard continued his work with solid-fuel rockets until the United States entered World War I.

By 1926, Goddard's experiments had advanced to the point that he was ready to fire the world's first rocket with a liquid-propellant sys-

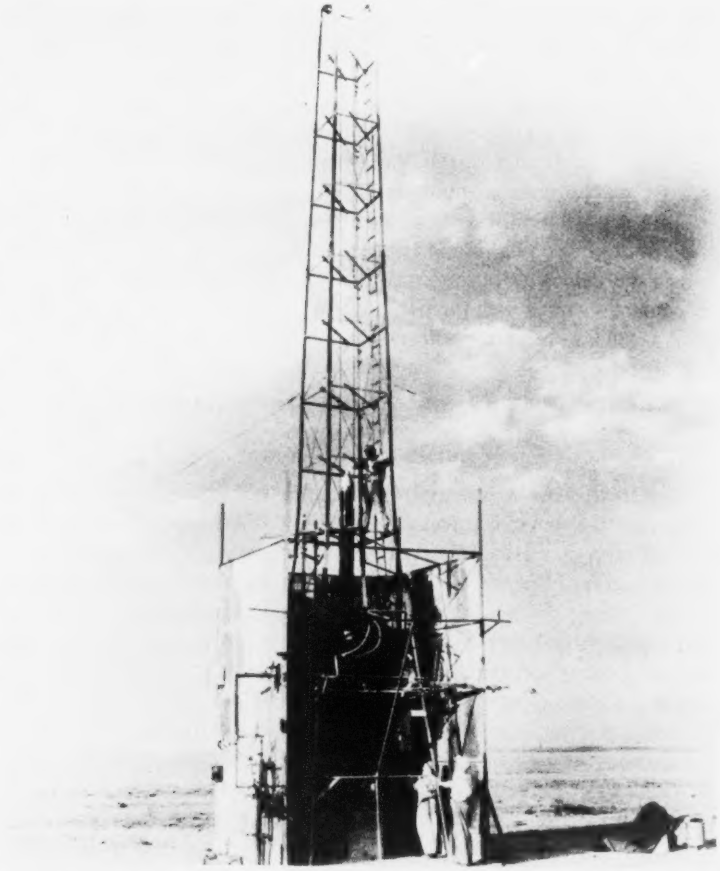

Figure 45. Dr. Robert H. Goddard fired the first liquid-fuel rocket in history from a small launch pad at Auburn, Massachusetts.

tem (Fig. 45). Although this rocket was only 10 feet long, its successful flight of 2½ minutes makes it the forerunner of today's modern space boosters. With Dr. Goddard at the time he signalled for ignition were his wife Esther, who served as his photographer, P. M. Roope of Clark University, and Henry Sachs, his igniter. The engine for this rocket rested on top with two propellant tanks below, one for gasoline and one for liquid oxygen. The propellants flowed under pressure through two 5-foot tubes to the engine. His next firing came in 1929 when he sent up an 11-foot liquid-fuel rocket with the first instrument payload, a barometer, thermometer, and camera.

After moving to Roswell, New Mexico, for more space in 1930, Goddard launched another 11-foot rocket which climbed to an amazing height of 2,000 feet and reached a top speed of 500 miles per hour. Following this flight, he became deeply concerned with problems of guiding and stabilizing rockets after lift-off. By 1935, he fired a gyroscopically stabilized rocket that reached an altitude of one and one-half miles at a speed of 550 miles per hour. Later the same year, two other rockets achieved speeds faster than the speed of sound. In 1936, Goddard continued his work on more advanced rocket components, such as cooling systems, vanes for inflight control, **gimbal steering***, motor clusters, catapult launching, and fuel pumps.

So advanced were Dr. Goddard's rockets by the time World War II began that only a few military officials could visualize the vast military potential of the rocket. A small group at the Guggenheim Aeronautical Laboratory of the California Institute of Technology had begun a program of rocket research in 1936. Two years later, Gen H. H. Arnold of the US Army Air Corps asked this group to study the problem of booster rockets for aircraft and, by 1941, the Air Corps had developed a solid-propellant rocket for assisted takeoff. But it remained for Germany to develop the technique for **long-range ballistic rocketry.**

One of the leading proponents of rocketry in Germany was Professor **Hermann Oberth,** an outstanding mathematician who was profoundly influenced by Dr. Goddard's work. Dr. Oberth began experimenting with liquid-propelled rockets in 1929. In detailed written reports, he described the characteristics required of a spaceship for human survival, research instruments needed in a spaceship, space suits, the use of a hammock for spacemen instead of a seat, and shoes with hooks to permit spacemen to move about in the weightlessness of space. Like Goddard, Oberth believed that a space station could travel in orbit around the earth. Oberth's research was the basis for much of the practical work in German rocket engineering after 1926.

Most of the first German experiments with rockets, especially liquid-fuel rockets, were conducted by members of the Society for Space Travel, of which Professor Oberth was a member. Another member of this group was **Wernher von Braun** who, at the age of 21, had already demonstrated his ability with the creation of a gyrostabilized rocket that flew 1¼ miles.

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* A steering mechanism that inclines in any direction.

When Adolph Hitler came to power in Germany in 1933, all rocket research was nationalized. German rocket scientists had two choices—to continue their rocket experiments under government direction or become enemies of the Third Reich. Those who stayed were confined to the secrecy of a little-known place on the Baltic Sea called **Peenemunde.** Here work began on high-thrust, ballistic rockets armed with explosive warheads. Later, the world would witness the flight of pilotless, guided missiles as they brought terror and destruction to the British people during World War II.

THE AIRPLANE AND WORLD WAR II

Adolph Hitler's rise to power during the late 1930s again changed the airplane's role from a peacetime transportation medium to a weapon of war. Unlike its status in World War I when it was at first of doubtful use as a military weapon, it became a dominant factor in the conduct of military operations during World War II. In the process, it not only experienced momentous changes in its design but also led man to the outer fringes of space. Major improvements in speed, performance, and endurance made it one of the world's most desirable forms of transportation.

The war years saw the arrival of pilotless missiles and long-range rockets, jet-propelled airplanes, and the practical helicopter. Even the ancient glider took on new dimensions as a troop carrier towed by powered airplanes. Although the aviation industry turned almost entirely to wartime production, the military required such a wide variety of aircraft that many machines were built for uses other than combat. The Armed Services required both light and heavy transport planes for troop deployment, training, spotting, and ambulance work. Many of these airplanes incorporated the latest innovations and, at the end of the war, became highly developed commercial airliners and other business aircraft. The United States led in transport production and therefore would continue to lead the world in commercial flying when the war ended.

So dominant was the airplane's role in World War II that it could not be classified simply as a fighter or a bomber. The strategic and tactical nature of the military mission required numerous basic types of airplanes and a variety of functions. The airplane adjusted to meet these requirements. Thus, fighter planes assumed responsibilities as light bombers or ground attack and reconnaissance vehicles. Light bombers often took over as long-range fighters, and so on. The major

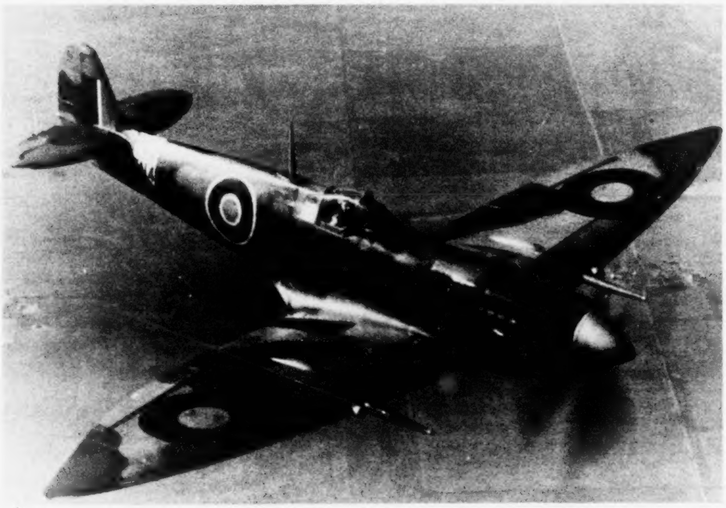
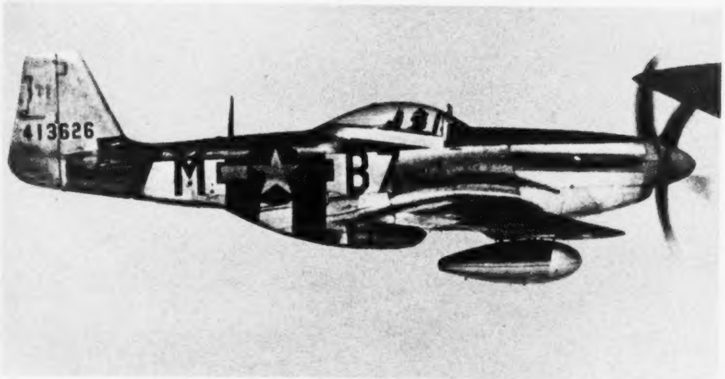


Figure 46. The British Spitfire was one of the most efficient fighter planes in operation at the beginning of World War II.

types of military aircraft that evolved during the war years may be classified generally as: light, medium, and heavy bomber; night-and day-fighters; fighter-bombers; transports and transport gliders; reconnaissance; liaison; observation; primary trainers; basic trainers; advanced trainers; training gliders; seaplanes; and helicopters. In addition to these manned aircraft, there were a number of wingless artillery rockets, winged pilotless missiles, and long-range rocket missiles. So immense was the race for superiority in the air that the American and British aviation industry alone produced more than 380,000 airplanes during the war.

Improvements in Speed, Performance, and Endurance

As the world approached war in the late 1930s, military airplanes in the United States, Great Britain, and Germany set new speed and altitude records. Engines now produced from 1,000 to 2,000 horsepower, and engineers designed machines capable of speeds above 400 miles per hour. By 1939, the airplane had established itself as a decisive weapon in any conflict. It proved its effectiveness when the German Luftwaffe decimated the Polish air force in the early morning



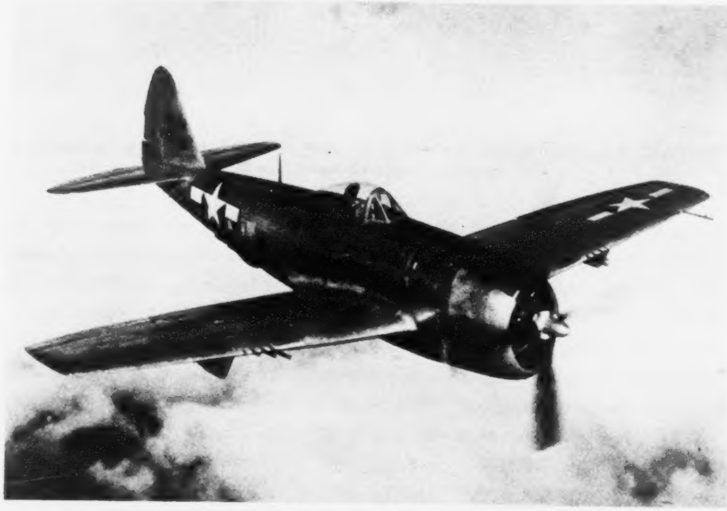


Figure 47. The North American P–51 Mustang and the Republic Thunderbolt were two of the most durable US single-seat fighters used in World War II. The Thunderbolt was the first 2,000-horsepower single-seat fighter built in the US.

hours of 1 September 1939. With undisputed air superiority, Germany took only 10 days to shatter Polish resistance.

The outstanding fighter airplanes at the beginning of the war were the British *Spitfire,* the German *Messerschmitt ME–109,* and the British Hawker *Hurricane.* With a 2,000-horsepower Daimler-Benz engine, the ME–109 set a world speed record of 470 miles per hour, a record that still stands for piston-engine airplanes. The ME–109, the *Spitfire,* and the *Hurricane* were single-seat, single-engine, propeller-driven fighters with normal speeds of about 350 miles per hour. For Great Britain, the *Spitfire* spelled the difference between victory and defeat at a time when the German air force greatly outnumbered the RAF. It had the distinction of being the only Allied fighter aircraft to remain in continuous production throughout the war (Fig. 46). Toward the end of the war, improvements in design and engine power increased its speed to more than 440 miles per hour.

One of the outstanding American single-seat fighters to enter the war was the North American Aviation P–51 *Mustang.* This was a high-speed fighter used for low-altitude flying and bomber escort. It was an all-metal, stressed-skin monoplane with a **laminar-flow wing design.*** On its maiden flight in 1941, it carried a 1,150-horsepower Allison engine and reached a maximum speed of 390 miles per hour at 8,000 feet. Later versions were powered by 1,680-horsepower Packard engines. These engines increased the *Mustang's* top speed to 442 miles per hour at 24,000 feet and enabled it to climb to 20,000 feet in 10 minutes. The *Spitfires* and the *Mustangs* were the fastest piston-engine fighters in the service at the end of the war.

Another significant American fighter airplane was the Republic Aviation *Thunderbolt.* This plane had the distinction of being the first 2,000 horsepower single-engine fighter built in the United States. It weighed 14,600 pounds and had a top speed of 427 miles per hour. From 1943 to the end of the war, it served regularly as an escort plane for the B–17 and B–29 bombers on daylight bombing raids over Europe (Fig. 47).

These were by no means the only fighter aircraft that flew during World War II. They are representative types to illustrate the impact of war on the design and technical proficiency of the airplane. During the pre-war years, designers concerned themselves primarily with the problem of inherent stability, while the airplane grew larger and more powerful. War brought constant demands for more speed, climbing ability, and range. Military airplanes became the pacemakers and, with more powerful engines and improved all-metal construction, all fighter planes now carried machine guns on the leading edge of their wings. Toward the end of the war, they flew at altitudes up to 40,000 feet with a climbing rate of 5,000 feet per minute. The Lockheed P–38 *Lightning,* for example, climbed at the rate of a mile a minute

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* A design that permits a nonturbulent airflow over or about an airfoil or other body.

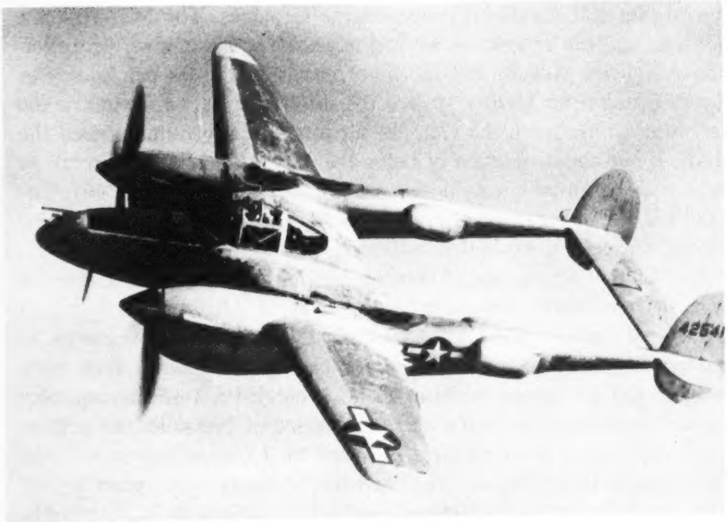

Figure 48. German pilots referred to the Lockheed P–38 Lightning as the "Fork-Tail Devil." It was one of the best fighter planes of the war.

and set a new record for speed when it flew across the United States in eight hours (Fig. 48).

At the outbreak of war, medium bombers, such as the *Blenheim, Beaufort,* and the *Junkers JU–88,* carried bombloads of about 1,500 pounds at speeds up to 270 miles per hour over a radius of 1,000 miles (Fig. 49). Heavy bombers, such as the *Heinkel 111* and the *Wellington,* had similar performances—speeds of 250 miles per hour, bombloads of 4,500 pounds, and a radius of 1,250 miles. These aircraft had crews of five men and defensive armament consisting of six machine guns. By the end of the war, medium bombers, such as the North American *B–25 Mitchell,* carried 2,000 pounds of bombs over a 500-mile radius at speeds above 300 miles per hour (Fig. 50). Another American medium bomber was the *Marauder,* a twin-engine monoplane with engines capable of developing 2,000 horsepower each. This bomber had tricycle landing gear and fully retractable wheels. Its internal bomb bay carried two 2,000-pound or four 1,000-pound bombs. It had an airspeed of 287 miles per hour at 5,000 feet and a landing speed of 100 miles per hour.

As the war progressed, a critical need developed for heavy four-engine bombers capable of day and night bombing. The Boeing Aircraft

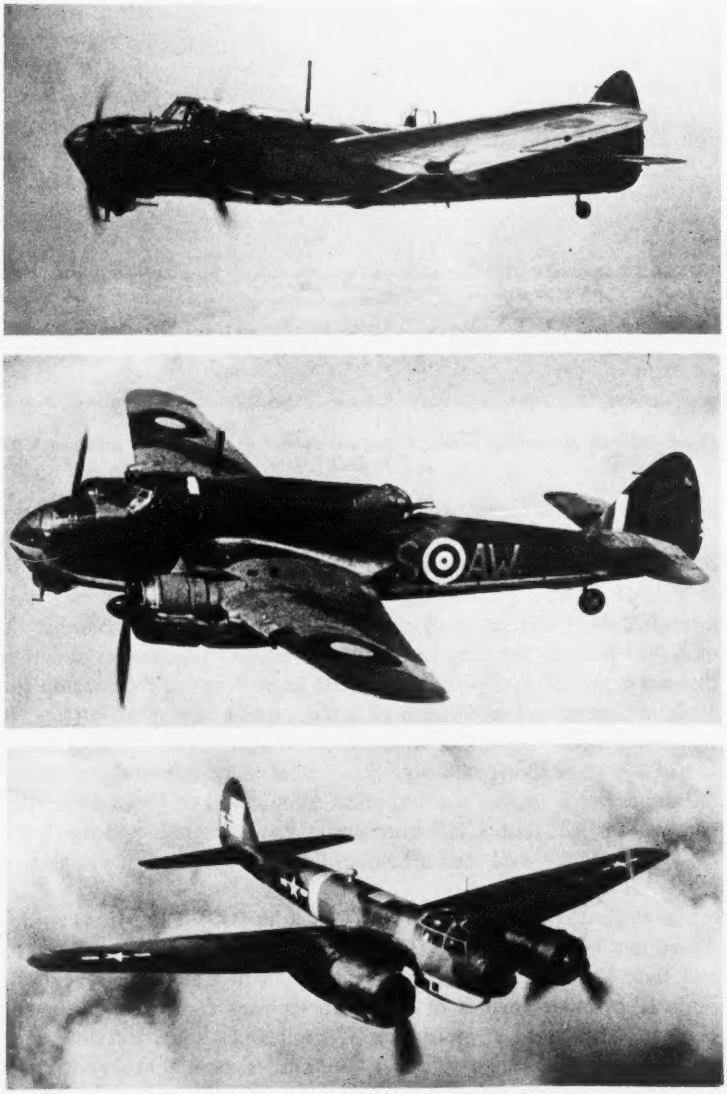

Figure 49. At the outbreak of World War II, medium bombers, such as the British Blenheim, the Beaufort, and the German Junkers 88 with American markings shown above, and heavy bombers, such as the Heinkel III and the Wellington, had similar speeds and ranges. Medium bombers carried bombloads of about 1,500 pounds, and heavy bombers carried loads of about 4,500 pounds.

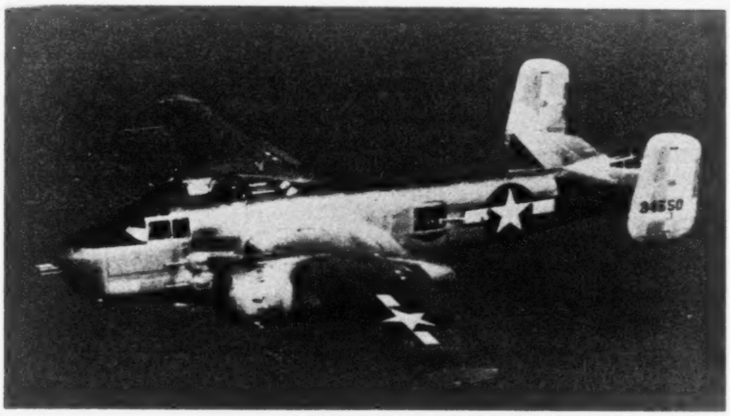

Figure 50. An outstanding American medium bomber was the North American B–25 Mitchell.

Company achieved additional fame for its creation of the *B–17 Flying Fortress* (Fig. 51). The first B–17 reached Great Britain in the spring of 1941 and went into action in mass daylight raids over Europe in July 1941. With 13 machine guns mounted in revolving turrets, this aircraft flew at altitudes up to 35,000 feet and could carry bombloads of 6,000 pounds for long-range flights, 12,800 pounds for medium distances, and 20,800 pounds for short trips. It could fly nonstop for 10 hours and then use wheel brakes for a quick stop after landing. It was an all-metal monoplane with a stressed-skin aluminum-alloy wing. It had a normal flying radius of 2,500 miles and an average speed of 220 miles per hour, but it could reach a top speed of about 295 miles per hour. It had four 1,200 horsepower radial engines and carried a crew of six to ten men, one a bombardier who operated in the plane's plexiglass nose.

An advanced version of the B–17 was the *B–29 Superfortress*, designed and built first by the Boeing Company in Seattle, Washington, and then by Douglas and Lockheed plants in California (Fig. 52). Four 18-cylinder engines of 2,000 horsepower each gave this giant bomber a top speed of more than 350 miles per hour, a ceiling over 35,000 feet, and a range well over 4,000 miles. Its fuel tanks carried a gasoline load that weighed eight times as much as its bombload. Like the B–17, this was an all-metal aircraft with fabric-covered control surfaces. A major improvement over the B–17 was its three separate pressurized compartments—one in the pilot section, one aft of the bomb bay, and one in the tail section. It carried a crew of 10 to 14 and had a maximum bomb capacity of 20,000 pounds in a bomb bay equipped with electrically operated doors. Before it was replaced by jet bombers, an advanced version of the B–29, the B–50, appeared in 1947. Four 3,500-horsepower engines gave this airplane a top speed of 400 miles per hour, a ceiling of 35,000 feet, and a range of 6,000 miles with 10,000 pounds of bombs. Proof of its efficiency came in 1949 when a single B–50, with the aid of inflight refueling, flew around the world without landing (Fig. 53).

These armored battleships of the sky were the last word in sturdiness and durability. Like the DC–3 transport, pilots reported numerous examples of their performance in the flak-filled skies over Europe. One story was told of a B–17 in a bombing raid on German factories. It returned to England with half its stabilizer blasted off by antiaircraft fire. Another reached its home base on its belly after having a gun turret smashed and its wing and rear fuselage pierced with 500 gaping bullet holes. But even these majestic planes later developed serious limitations. As fighter plane speeds improved beyond 500 miles per hour, the piston-engine bomber's slow speed made it highly vulnerable to attack. At altitudes of 20,000 feet, their 20-foot propellers lost too much power in the thin atmosphere. Even with superchargers, they

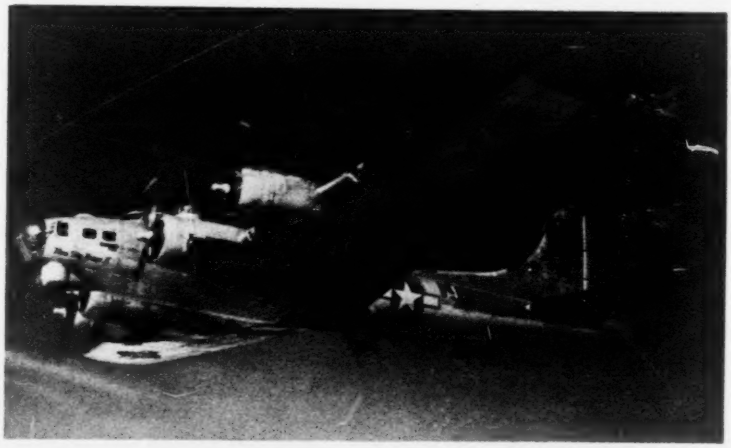

Figure 51. The B–17 Flying Fortress was the first American four-engine heavy bomber. With 13 machine guns mounted in revolving turrets and bombloads up to 20,800 pounds, it was an airborne fortress that flew in mass daylight bombing raids over Europe in World War II.

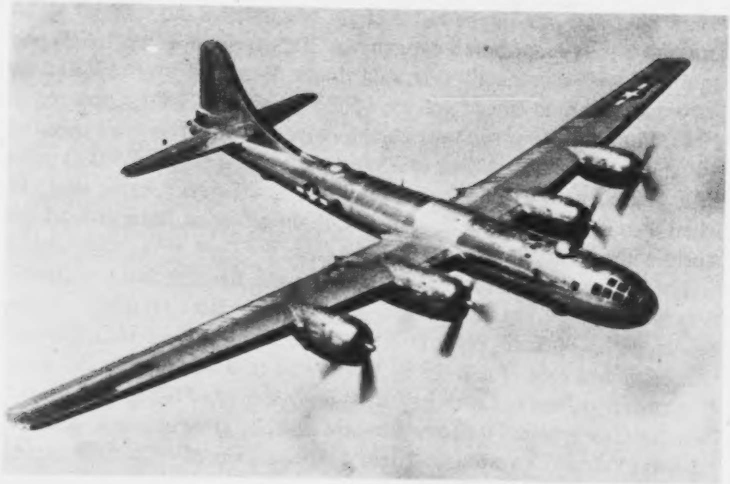

Figure 52. The B–29 Superfortress was the largest bomber in operation during World War II and was the first aircraft in the world equipped with remote-controlled, power-operated gun turrets.

could not push these huge aircraft beyond speeds of 435 miles per hour. Other developments would be necessary before higher speeds could be achieved.

Pilotless Missiles and Long-Range Rockets

Just as the Allies gained control of the air, Germany alarmed the world with the introduction of a so-called flying bomb. The first evidence of this weapon was a small batwing plane without a propeller that buzzed through a formation of B–17 Flying Fortresses one spring day in 1944. Startled crewmen could only gasp in astonishment as the ghostly apparition passed quickly out of sight. They had just seen their first pilotless missile. The work of Wernher von Braun and other German scientists was paying off. Germany had become the first nation to use guided weapons.

This was the first of two types of **guided missiles** developed by the Germans and labeled the V–1 or "vengeance weapon," used to retaliate for British bombing raids against Germany. The V–1 was a pilotless monoplane equipped with low, **swept-back wings** and powered with a simple **pulse-jet engine***. It had a range of 150 miles, a speed of

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* A kind of jet engine having neither compressor nor turbine, but equipped with vanes in the front end which open and shut, taking in air to create power in rapid periodic bursts rather than continuously.

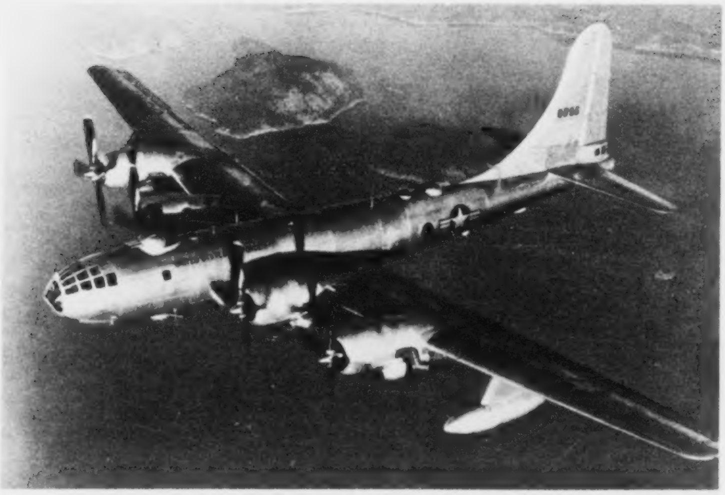

Figure 53. The B–50 was the last piston-engine aircraft produced by the Boeing Company.

400 miles per hour, and a payload of about one ton of explosive. Launched from specially designed catapults, some 2,400 of these flying bombs fell on London during the summer of 1944.

The most significant development in guided missilery came with Germany's launching of the V–2 missile some three months after the flying bomb attacks. After years of research, the Germans had developed a liquid-fuel rocket that could propel a missile to a pinpoint target. During a test in 1942, a V–2 reached an altitude of 300,000 feet at an average speed of about 5,000 feet per second (five times the speed of sound). Two years passed before the first V–2 struck the southeast coast of Great Britain in September 1944. Before the war ended in 1945, the Germans fired more than 3,000 of these rockets against Britain and the cities of Brussels, Antwerp, and Liege in the Low Countries.

Like Dr. Goddard's liquid-fuel rocket, the propellants for the V–2 were alcohol and liquid oxygen. This weapon carried nine tons of fuel and a one-ton warhead for a total weight of about 12.7 tons. It was 47 feet long and 5½ feet in diameter, and it developed 26 tons of thrust. It had a range of 200 miles, a total flight time of 5 minutes, and a maximum ceiling of 60 miles. It reached its top speed of 3,500 miles

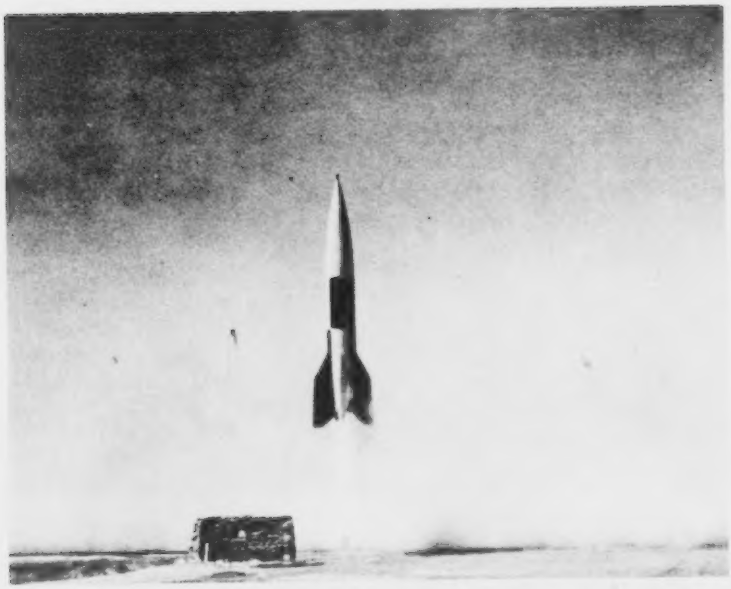

Figure 54. A V–2 missile leaving the ground after ignition. The V–2 was a liquid-fuel rocket that reached a speed of 3,500 miles per hour.

per hour at an altitude of 25 miles (Fig. 54). For the first 60 seconds of its flight, sets of vanes in the rocket jets and on the fins controlled the flight path. The vanes, in turn, were controlled by gyroscopes timed to bring the missile into its proper trajectory for targeting.

The Germans developed the V–2 and other guided missiles primarily for offensive operations during the years 1943 to 1945. But, as the war wore on, they seriously considered the defensive potential of these missiles against the mass air attacks of the American bombers. Other nations quickly recognized the significance of these missiles in warfare, particularly since nuclear weapons had become operational. Within 10 years after the war, for example, the United States had an entire arsenal of guided weapons in operational readiness. Such familiar names as *Nike, Terrier, Matador, Navaho,* and *Bomarc,* in no uncertain terms, signalled the coming of the Aerospace Age when man not only would fly in his aerial machines but also would send them through the air with complicated electronic control systems.

The Jet Takes Over

One of the most important aeronautical developments of World War II came with the first flights of the Heinkel HE–178 in 1939 and the Gloster-Whittle in 1941. These flights mark a milestone in the history of aviation equally as important as the Wright brothers' first flight in 1903. Just as centuries of research preceded the work of Wilbur and Orville Wright, the flight of the **Heinkel HE–178** was the result of long years of research in jet propulsion. French engineers had experimented with jet engines as early as 1912, but they lacked proper metals and could not produce enough thrust to push an airplane through the air. In 1923, NACA engineers in the United States studied the jet engine but concluded that it was too heavy and inefficient for use on airplanes. To German engineers must go the credit for making the first practical application of jet propulsion in an airplane. They not only created the first practical jet-propelled airplane in the HE–178 but increased the airplane's overall efficiency with swept-back wings that permitted a speed of almost 600 miles per hour.

Pilots were delighted with the prospects of jet flight. They would now fly without engine vibration and the slashing sound of propellers. Once it reached the production stage, the jet engine presented a fundamentally simple design with one-tenth as many moving parts as the piston engine. There was no longer a need for camshafts, pistons, connecting rods, and control mechanisms. The engine was a simple cone-shaped structure that admitted air through an open front end and expelled it through a tapered exhaust jet at the rear. Compressed air and fuel were injected under pressure into a firing chamber in the center of the cone. Turbines at each end were geared to a single drive shaft. Hot gases turned the turbine in the rear, and the turbine on the front compressed the air that entered the fuel chamber. This was the basic design of the first operational turbojet engine. Modern jet engines operate in much the same manner.

After the HE–178 research plane had proven that jet engines could be used efficiently, the German aircraft industry in 1941 rushed to completion one of the war's most spectacular airplanes—the Messerschmitt ME–262 *Schwalbe* (Fig. 55). This aircraft entered service in 1944 first as a fighter and then as a light bomber, but it came too late to affect the outcome of the war. Although it was the only jet fighter used in combat against the Allies, it proved to be a deadly weapon. With two **axial-flow*** *Jumo* engines and broad swept-back

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* A jet engine in which the flow of air is along the longitudinal axis of the engine.

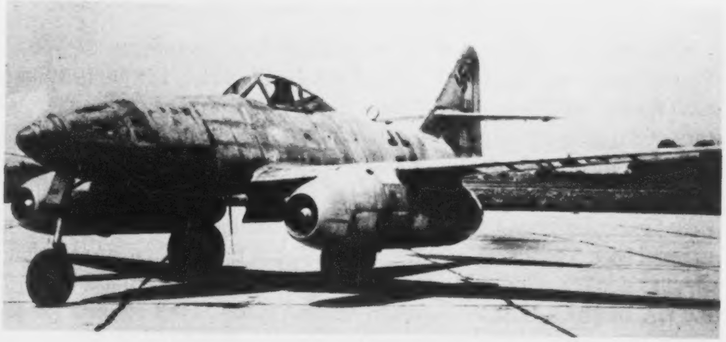


Figure 55. The German Messerschmitt ME–262 Schwalbe was the world's first operational jet fighter.

wings, this remarkable airplane flashed through the air at speeds well above 500 miles per hour and performed efficiently at 40,000 feet.

Even as the war drew to a close in 1945, German scientists produced other noteworthy jet aircraft. A number of small "Volksjager" jet fighters—the Heinkel HE–162 *Salamander*—became operational in 1945 with speeds of 520 miles per hour. The world's first heavy jet bomber—the Junkers JU–287—took to the air at a speed over 500 miles per hour with a bombload of 8,800 pounds. This huge plane had swept-forward wings and four engines with auxiliary takeoff rockets. Even more spectacular was Germany's production of the world's first rocket-jet airplane—the Messerschmitt ME–163 *Komet* fighter which saw action against Allied bombers in 1944. With swept-back wings and a Walter liquid-fuel rocket motor, this airplane reached a speed of 590 miles per hour and climbed to 30,000 feet in 2½ minutes.

The United States showed only a limited interest in jet propulsion before 1941. Gen H. H. Arnold of the US Army Air Corps watched the first flight of the Gloster-Whittle E–28/39 and immediately arranged for copies of the Whittle engine in the United States. Under top secret orders, a B–17 Flying Fortress brought a Whittle engine to the gas turbine division of the General Electric Company. While General Electric engineers built two turbojet engines based on the Whittle design, Bell Aircraft Company constructed the airframe. By 1944, the Bell XP–59A *Airacomet* was ready for its first flight at Muroc test base in California, but it had to be towed under camouflage to the flying field (Fig. 56).

During the first test flights over the Muroc desert, pilots in flight training at a nearby bomber base could not believe what they saw streaking across the skies. They returned to base and reported their encounter with a strange mid-wing monoplane without propellers. Even more astounding, the pilot wore a derby hat! At first, their medical officer mumbled something about training fatigue and ordered a rest. Later, the doctor and his patients learned that the pilot in the nonregulation hat was flying the first jet-propelled airplane in the United States. From this point on, events came in rapid succession, and, by late 1944, the Lockheed Company had produced the sleek P–80 *Shooting Star,* a single-engine jet with a speed of 575 miles per hour (Fig. 57). In April 1945, one month before the end of World War II, the first combat force of American jet fighters appeared in Europe ready to meet the ME–262s in battle. The war ended before these battles could take place.

The Practical Helicopter

Long before the advent of the modern, high-speed airplane, flying enthusiasts considered the problem of reducing the distance for airplanes to land and take off. But as the speed and size of the airplane increased, the problem became more acute, particularly in small, unprepared areas. Even with such landing aids as flaps, wheel brakes, re-

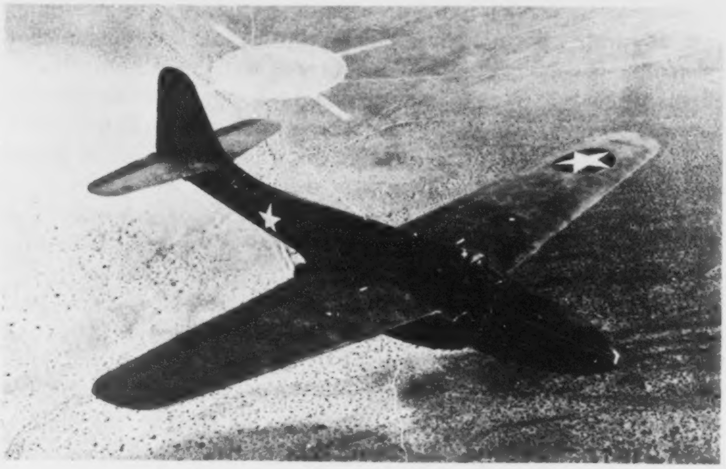


Figure 56. The Bell XP–59A was the first jet-propelled aircraft to fly in the United States. It was powered by two General Electric 1-16 engines based on the Whittle turbojet design.

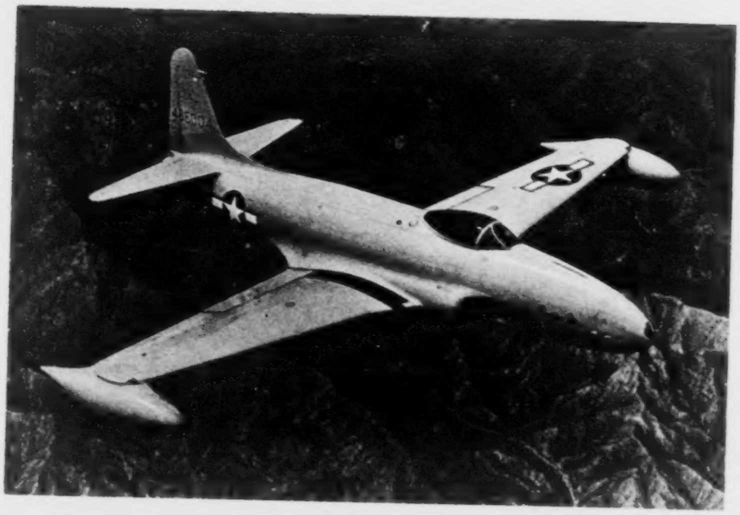
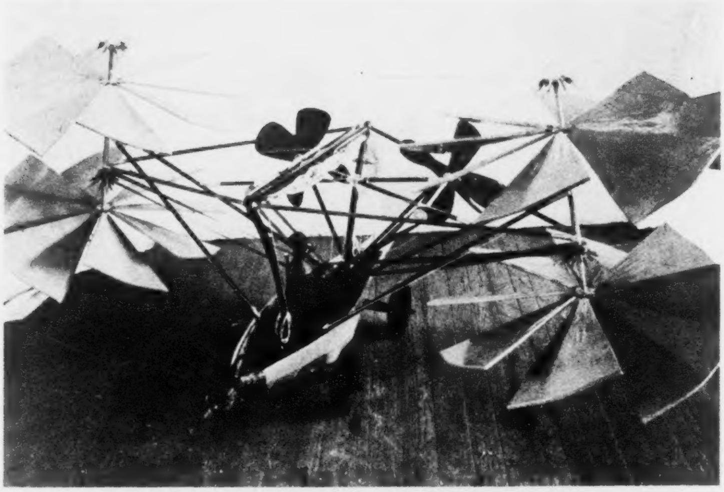


Figure 57. The Lockheed P–80 Shooting Star was an early American jet fighter that later became the F–80 Shooting Star used during the Korean War.

versed thrust, and parachutes, modern, heavily loaded airplanes still require large areas for landing and taking off. The main runways of a modern airport may stretch for two miles or more.

The obvious solution to the problem of space is to raise an aircraft vertically with a horizontally rotating propeller. For years, men considered the possibility of attaching a rotor or wide-bladed propeller to an aircraft and moving the craft up and down with rapid rotations of the rotor blades. Their primary concern, of course, was not to achieve speed. They searched for an airplane that would move slowly or remain motionless in the air. They wanted a machine that would move in any direction—up, down, forward, backward, or sideways. The term "helicopter," derived from the Greek words for screw and wing, was the first reference to such aircraft.

Leonardo da Vinci probably made the first recorded sketch of a helicopter as early as the year 1500. His design called for a curved blade turned at a high speed so that it would "form a screw in the air, and climb high." Later, in 1792, George Cayley built a toy helicopter with a metal rotor that carried it 90 feet into the air (Fig. 58). But, in 1923, a Spaniard, **Juan de la Cierva,** built the first practical airplane with some of the characteristics of a helicopter, an autogiro. This machine had the same design as an ordinary airplane, except that it used



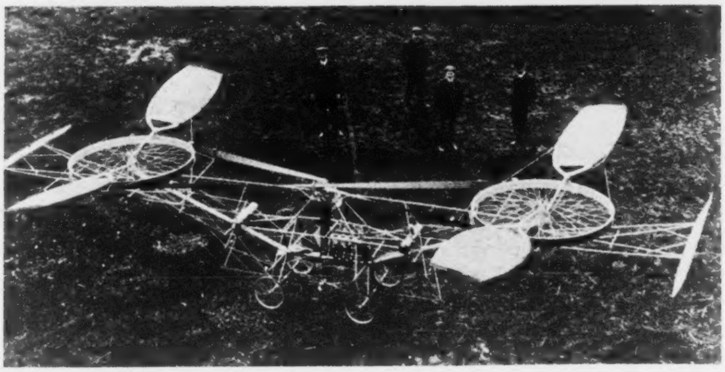


Figure 58. The top photograph shows the first helicopter, built in 1842 by George Cayley. The lower picture shows a helicopter built by Paul Corner in the year 1907.

a huge windmill rotor instead of wings. It differed from the true helicopter in the sense that its rotor was not power-driven. Although the rotor blades were attached to a vertical shaft, they were kept in motion only by the forward movement of the whole aircraft, which was driven by a tractor propeller.

By 1935, Cierva achieved vertical takeoff similar to that of the helicopter. He feathered the rotor blades to a rotating speed 25 percent

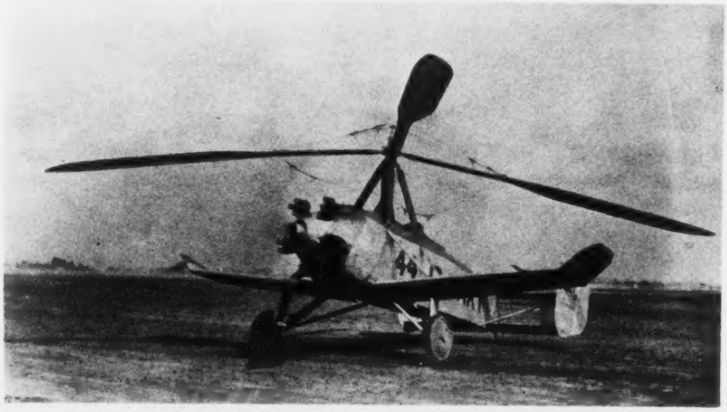


Figure 59. The Cierva autogiro had the characteristics of both a helicopter and an airplane. It had a propeller, fuselage, and a tail section, but it had a huge windmill rotor instead of wings.

greater than was required for flight. He then declutched the rotor from the engine and simultaneously increased the pitch of the blades. For a brief interval, he had a lift greater than the weight of his machine. As a result, he could rise vertically in his autogiro to a height of 20 to 30 feet before he began his forward flight (Fig. 59).

Cierva's success with the autogiro stimulated further interest in vertical flight and led directly to the development of the practical helicopter. The first fully operational helicopter was the **Focke-Achgelis FW–61** built by German engineers in 1936. This helicopter had a standard propeller on the front to move it forward, but, instead of wings, it had a metal framework on each side topped by a rotor. It could remain in the air for 1 hour and 20 minutes, fly 89 miles in a straight line, climb to an altitude of 11,240 feet, and reach speeds as high as 75 miles per hour. The Germans used a later version of the FW–61, the Focke-Achgelis FA–223, during World War II to supply troops on service in mountainous areas. This helicopter had two large rotors driven by a 1,000-horsepower Bramo BMW 323 engine. It weighed 8,600 pounds and carried a payload of 1,760 pounds. It was the first production helicopter in the history of aviation.

The helicopter that ended the popularity of the autogiro family, however, came as the direct result of the work of a Russian-born American, **Igor Sikorsky.** He abandoned his interest in multiengine bombers and seaplanes and returned to his primary concern—the rotary-wing airplane. It was Sikorsky who developed the helicopter into a practical and controllable aircraft.

Sikorsky began his work with the basic idea that a single-rotor helicopter would be more efficient than the twin-rotor type. To counter torque, he included a smaller tail-rotor that operated on a horizontal axis. The first Sikorsky helicopter to go into production for military use was a two-seat trainer known as the R–4B. This machine had a three-blade main rotor 38 feet in diameter and a three-blade controllable-pitch rotor 8 feet in diameter. The smaller rotor operated on an outrigger extension of the fuselage. A single engine drove both rotors through a system of transmission shafts and gear boxes. The engine was a 185-horsepower radial air-cooled Warner which gave this helicopter an overall speed of 75 miles per hour.

It made a spectacular flight when the Sikorsky Company delivered it by air from Bridgeport, Connecticut, to the Army base at Wright Field, Dayton, Ohio, in 1942. It covered a distance of 761 miles in a total flight time of 16 hours and 10 minutes. The flight was similar to Paulhan's flight from London to Manchester in 1910. A special train with mechanics and spare parts accompanied Paulhan's flight. A car with mechanics and spares also followed the R–4B to Dayton. Even so, this flight marked the arrival of the helicopter as a practical flying machine. The next decade saw the creation of as many as 30 different types of helicopters.

From 1942 until the end of the war in 1945, the United States trained more than 100 pilots in Sikorsky helicopters for use in the Pacific. Although they did not see action, the helicopters quickly gained acceptance as larger models, such as the Piasecki PV–3, took to the air. Further developments in helicopter design came in 1943 when an Austrian firm produced a helicopter with a jet-propelled motor. An engine in the fuselage forced a compressed mixture of fuel and oxygen through hollow rotor blades to combustion chambers at the rotor tips. With this innovation, the helicopter hovered in the air at one time for a period of 50 hours. The jet system eliminated the need for tail rotors used on the Sikorsky helicopters to counter torque reaction.

By the end of World War II, the helicopter had proven that it had a definite role to play in the Aerospace Age (Fig. 60). Its principal advantage was that it could travel at low speeds, operate in a small area on the ground, and hover over inaccessible or isolated areas. During World War II, the "Whirlybird" became an invaluable aircraft for observing, carrying messages, and rescuing wounded men. And, in

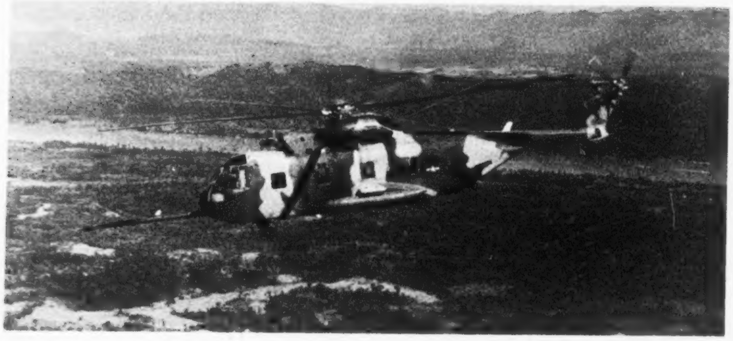


Figure 60. A modern USAF helicopter—the HH–3E Jolly Green Giant.

Korea, it again served in a vital military role. Today, in Southeast Asia, the helicopter is an indispensable element of military operations, particularly in rescue, observation, and reconnaissance. Its peacetime role is familiar to everyone—mail delivery, the rescue of people marooned by floods and other natural disasters, assistance in traffic control, crop dusting, and the retrieval of astronauts.

Civil Transport Aircraft

Numerous international networks of civilian air routes had been established by 1939. Strangely enough, there were no established air routes over the great oceans of the world. Without some reliable link between the United States and Europe, civilian air travel could not be regarded as a mature mode of travel. Although a number of transatlantic crossings were made in the early 1930s, there were no civil aircraft that could operate economically beyond the limit of 2,500 miles. The average range and speed of large airliners in 1939 was 1,000 miles and 175 to 210 miles per hour.

The most noteworthy efforts in the United States to establish transatlantic services were made by Pan American Airways. As early as 1927, this airline company had established air routes in the Caribbean, South America, and certain islands in the Pacific. In 1935, the Pan American *China Clipper* made the first scheduled airmail flight across the Pacific. Pan American made a few experimental commercial flights to Europe in 1939, using Boeing B–314 flying boats. The *Yankee Clipper* made the first of these flights from Long Island via Lisbon to Marseilles, France. Further developments in transoceanic travel would come only after the airplane increased its range and speed.

Throughout World War II, the backbone of Allied transport aircraft was the twin-engine DC–3. The significant development came during the war with the appearance of large four-engine bombers. These aircraft, particularly those produced in the United States, set the style for all modern civil transports and made a routine performance of transoceanic travel. The B–29 *Superfortress* set the pace in 1941 when pilots made regular flights across the North Atlantic to Great Britain. More than any other single achievement, these flights convinced the public that the whole world was now within the practical range of the airplane. This led to the creation of an entire new series of four-engine transports, used first in military service and then as civilian airliners.

One of the most important new four-engine airliners was the Douglas DC–4 *Skymaster* (military C–54), the plane that set the standard for a generation of four-engine transports. The DC–4 made its first flight in 1942 and went into military transport service in 1943. It had a wing span of 117½ feet, a single fin and rudder, and four engines of 1,350 horsepower each. With a six man crew and 42 passengers, this plane could cruise at a speed of 200 miles per hour for distances up to 1,500 miles. A second important transport was the Lockheed *Constellation* (military C–69) with a snake-like fuselage and a triple tail unit. With four radial engines of 2,200 horsepower each, the *Constellation* carried 51 passengers at a cruising speed of 280 miles per hour for distances up to 2,000 miles. Both the *Constellation* and the DC–4 had reversible propellers and power-boosted controls (Fig. 61).

Another large airliner to come out of the war was the Boeing *Stratocruiser,* which served as both a civil and military transport. This airliner developed as a direct progeny of the B–29 *Superfortress.* It carried a 7- to 10-man crew and 60 to 100 passengers at a speed of 270 miles per hour over distances of 3,000 to 3,500 miles.

In addition to revolutionary changes in airplane design, speed, and range, the war brought vast improvements in navigational and landing facilities. In the United States, for example, night flying before the war was possible only with the creation of a transcontinental beacon system, consisting of 2 million candlepower revolving beacons located 10 miles apart on the flight course. At the base of each beacon was a lighted concrete arrow that indicated the route. Between the main airdromes were intermediate landing fields about 30 miles apart for emergency and refueling purposes. Pilots maintained radio communication with the nearest airdrome or landing area. Main landing areas included boundary lights, flood lights, and illuminated wind direction indicators.

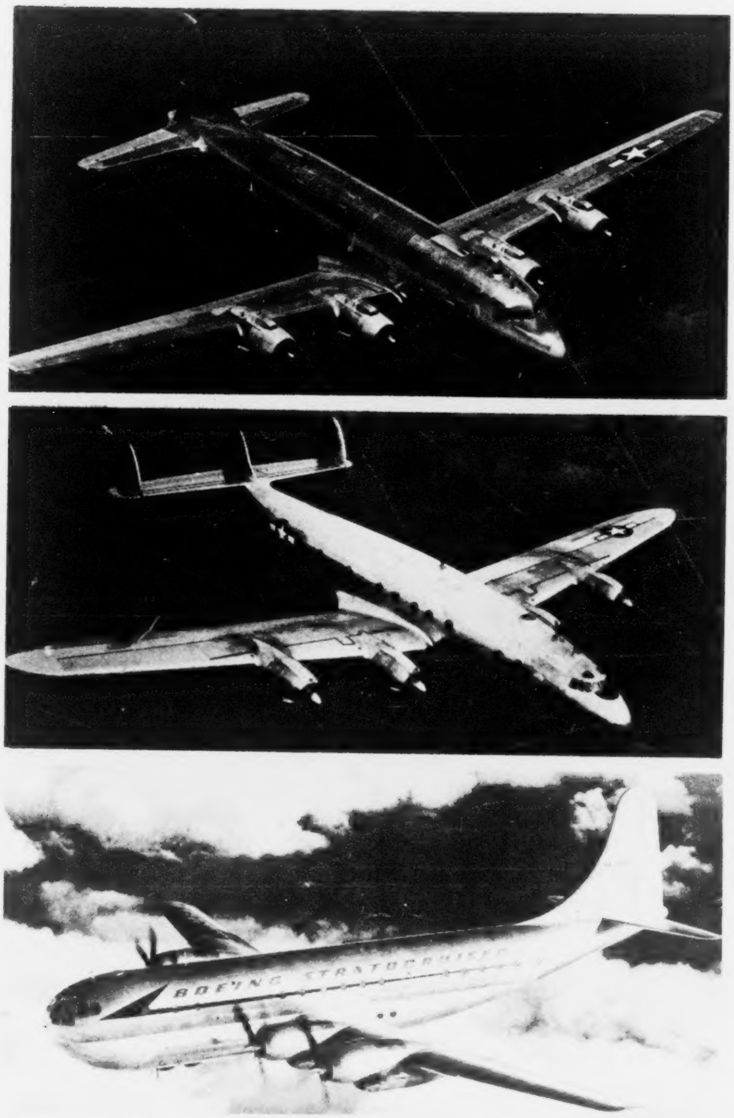


Figure 61. The Douglas DC–4 Skymaster (C–54), the Lockheed Constellation (C–69), and the Boeing Stratocruiser set the standard for a generation of civilian and military transport aircraft. Both the Skymaster and the Constellation had reversible propellers and power-boosted controls.

Improved radio and radar communications eliminated the need for these elaborate marking systems, but the modern airport maintains some of the most efficient lighting systems in the world. Standard equipment includes identification beacons, runway lighting for takeoff and landing, boundary lighting to define airport limits, and taxi-way lighting between runways and parking areas. Shortly after the war, the airlines established a new Instrument Landing and Ground Approach radar system which enables pilots to fly in weather that would have canceled flights in the prewar years. Later would come the BLEU Autoland—a pilot-monitored automatic landing system. These and numerous other improvements were making manned flight one of the safest modes of transportation since the invention of the wheel.

By 1945, airplanes with reasonable payloads had ranges of more than 3,000 miles and cruising speeds well over 300 miles per hour. As fears of flying declined, civil air transport expanded rapidly in the postwar years. By 1960, major airlines reported more than 100 million passengers and only 850 casualties, as compared with thousands of lives lost each year in automobile accidents. The airplane had not reached its apex, however. Other momentous developments were just around the corner. These developments would usher in the Aerospace Age when man would shatter the sound barrier in winged jets and boost himself by rocket into the outer reaches of space.

Although man had understood and used the principle of jet propulsion for centuries, it was not until the period of the twenties and thirties that jet propulsion became a practical reality for airplanes. During the same period, modern rocketry added a new dimension of power that not only brought strange new weapons of war but also enabled man to send flying machines to the outer fringes of space.

In England, Frank Whittle produced a gas turbine jet engine that ultimately led to the Gloster-Whittle E–29/39, one of the two airplanes that flew with practical jet propulsion systems in the early stages of World War II. In Germany, Hans von Ohain flew the world's first jet-propelled fighter plane. Toward the end of World War II, limited numbers of German jet fighters took a heavy toll of Allied bombers, but they came too late to affect the outcome of the war. Experimentation by civil adventurers brought the airplane into being, but wartime requirements for power and speed made it the world's fastest transportation medium.

THE AEROSPACE AGE

Adolph Hitler's rise to power in Germany again forced the airplane to become a weapon of war. Unlike its role in World War I, the airplane played a dominant role in military operations during World War II. Although jet aircraft and rockets had little, if any, effect on the outcome of World War II, they signalled the approach of an entire new era in manned flight. Furthermore, they brought the moon and distant planets within the range of man-made machines. By 1945, four-engine transports could fly more than 3,000 miles at cruising speeds well above 300 miles per hour. Smaller planes were approaching the sound barrier with speeds over 500 miles per hour. People now flew coast to coast in 8 hours as compared with 48 hours in the prewar years. Even with his wartime achievements, however, man was only in the beginning stages of vast new dimensions in air power. Further momentous developments would come as he crossed the threshold into the Aerospace Age.

WORDS AND PHRASES TO REMEMBER

axial-flow engine
gas turbines
gimbal steering
guided missiles
jet engines
laminar-flow wing design
liquid propellants
long-range ballistic rocketry
multistage rocket systems
Newton's third law of motion
piston engine
pulse-jet engine
solid-fuel propellants
swept-back wings

NAMES TO REMEMBER

Cierva, Juan de la
Focke-Achgelis FW–61
Goddard, Robert
Heinkel, Ernst
Heinkel HE–178
Oberth, Hermann
Peenemunde
Sikorsky, Igor
Tsiolkovsky, Eduardovitch
Von Ohain, Hans
Von Braun, Wernher
Whittle, Frank

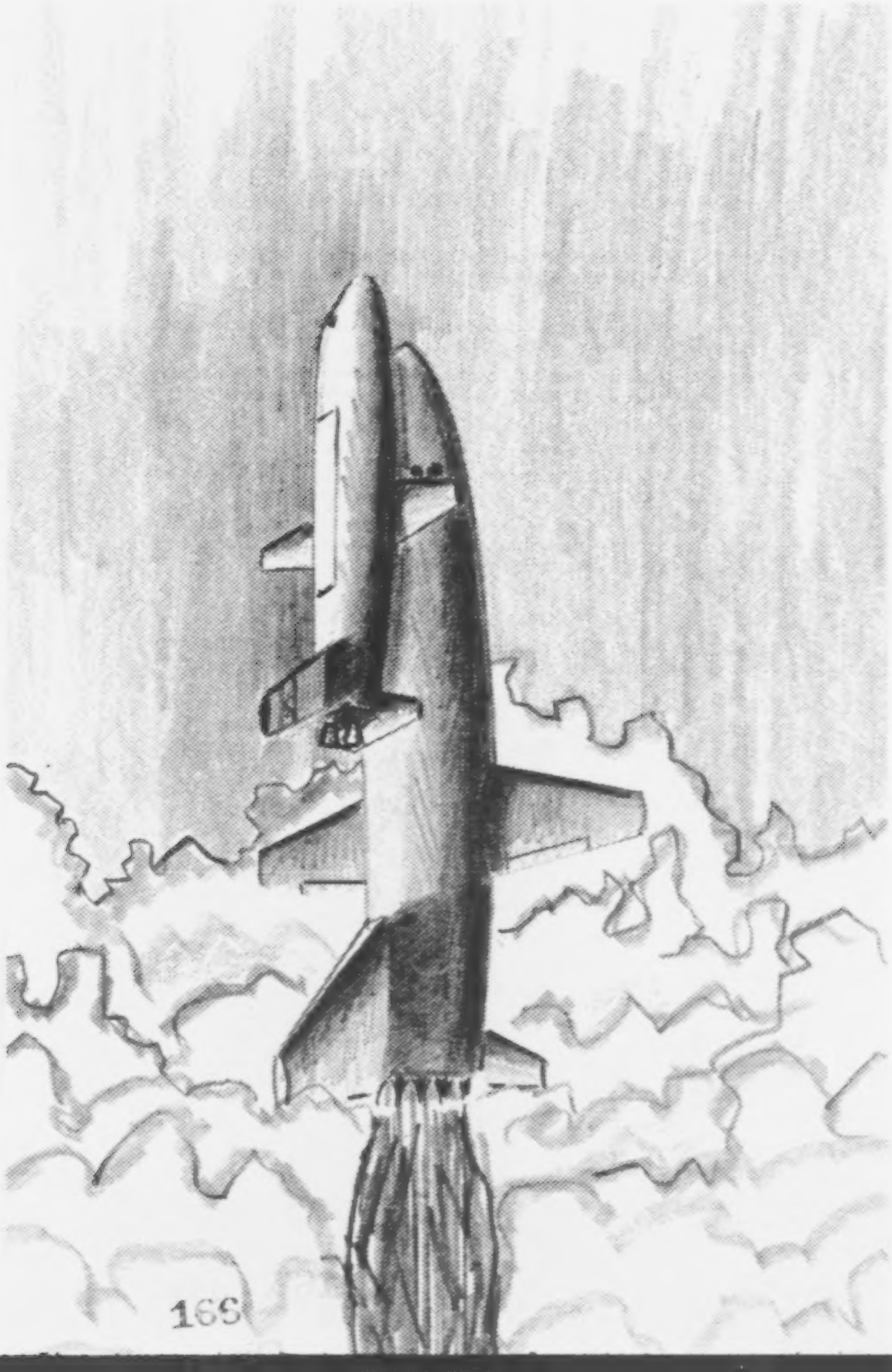
QUESTIONS

1. **What two major events in the 1930s brought further rapid developments in the airplane as a transportation medium?**
2. **In what way do jet rocket engines apply Newton's third law of motion? How do they differ?**
3. **Discuss the significant events that occurred in the application of the gas turbine to aircraft propulsion in the twenties and thirties.**

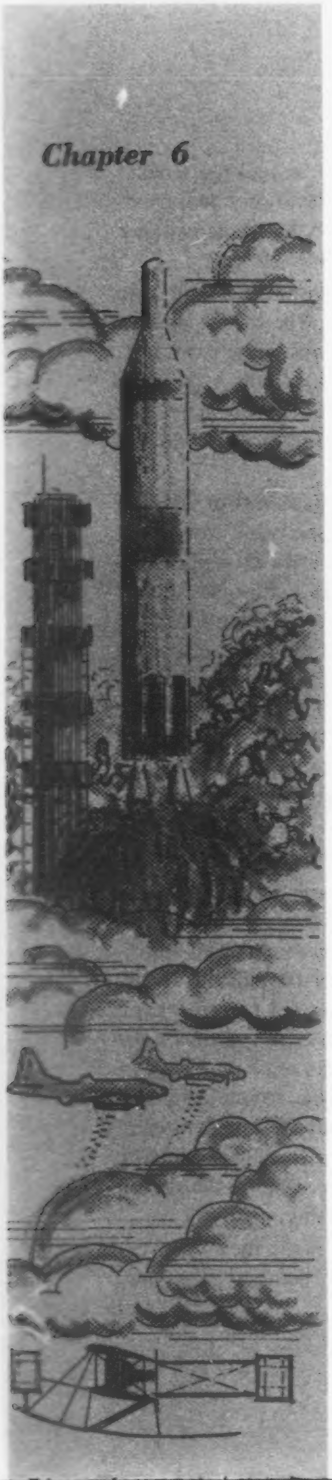
4. **Discuss the contributions of Eduardovitch Tsiolkovsky, Robert Goddard, and Hermann Oberth to the development of modern rocketry.**
5. **Distinguish between the role of the airplane as a military weapon in World War I and in World War II.**
6. **Describe some of the outstanding military airplanes used in World War II and show how wartime demands brought improvements in the airplane's efficiency.**
7. **Discuss the technological significance of the V–1 and V–2 guided missiles introduced by Germany in World War II.**
8. **What was the name of the first jet-propelled airplane? What other famous jet aircraft became operational toward the end of World War II?**
9. **What is the difference between the mechanical design of a jet airplane and a piston-engine airplane?**
10. **Trace the development of the modern helicopter, giving special attention to the contributions of Juan de la Cierva and Igor Sikorsky.**
11. **What effect did the appearance of large four-engine bombers in World War II have on civil air transportation? Describe the most outstanding four-engine airliners to come out of World War II.**

THINGS TO DO

1. If possible, visit a modern airport and observe jet aircraft in flight. Better yet, take a flight on either a modern jetliner or a private jet aircraft.
2. Construct a model rocket of your own.
3. Continue your scrapbook with pictures of outstanding American fighter and bomber aircraft of World War II.
4. Take a flight on a modern helicopter.
5. Add famous four-engine airliners of the post-World War II period to your scrapbook.



Chapter 6



The Modern Age

THIS CHAPTER summarizes major developments in aviation and spaceflight in the decades since World War II. It begins with a discussion of significant aerodynamic and structural improvements in aircraft design as the speed of the airplane increased. It describes further revolutionary changes brought by jet engines in the design of military and commercial aircraft and cites examples to show how far the airplane has advanced since the first glider flights. It also includes a discussion of the events that brought man into the Aerospace Age. The chapter concludes with a glimpse at future possible developments in aerospace. When you have studied this chapter, you should be able to do the following: (1) explain why the term "aviation" is no longer used in reference to modern flight vehicles; (2) identify and describe major aerodynamic and structural improvements that have occurred in the airplane since World War II; (3) list and describe some of the outstanding military and commercial jets of the modern era; (4) trace the events that led to the Apollo flights; and (5) discuss and evaluate possible future developments in aerospace.

BEFORE the advent of the airplane, geographical and other physical barriers limited man to surface travel by land and water. The airplane freed him from these limitations and carried him to the upper limits of the earth's atmosphere. He then confronted another barrier beyond which the airplane could not carry him. Already at his disposal, however, were new and revolutionary sources of power that boosted his flight beyond the earth's atmosphere into space and brought the most distant points on the earth no further than 24 hours away. The term "aviation" is no longer an adequate reference to the new generation of flight vehicles. Aviation is still applied to planes with jet engines but is not applied to rockets. Rocket engines took man into space after penetrating the lower, denser atmosphere where airplanes travel. Thus, to describe the whole expanse of this new environment, the term "aerospace" came into use.

Modern man views flight in the context of **aerospace,** a total area that stretches outward beyond the earth's surface. The lowest portion of this area consists of loosely defined layers comprising the earth's atmosphere. Beyond this area is outer space, a vast, infinite void filled with the planets, stars, meteoroids, other materials, and an increasing number of manmade objects. Aerospace encompasses both the atmosphere and outer space.

Modern man has circled the earth in orbiting spacecraft in 90 minutes. He has sent thousands of manmade objects into orbit around the earth and others to neighboring planets. He has flown in winged aircraft to the fringes of space and returned to the earth. He streaks across the skies in high-performance military aircraft at three times the speed of sound, and he blasts himself by rocket to the moon at speeds above 20,000 miles per hour. He travels as a matter of routine in commercial airliners that transport more than 500,000 passengers daily at the rate of 10 miles per minute. These are the events that symbolize what scientists describe as the greatest adventure in man's existence—the Aerospace Age.

DEVELOPMENTS SINCE 1945

The decades since World War II have witnessed developments in aviation and spaceflight so numerous and far-reaching in their impact that only a brief account can be given of their dimensions. The stimulus, of course, was the practical application of jet propulsion to airplane engines **(turbojet* and turboprop).**** This led to supersonic flight, the growth of air transport, and the creation of the world's most powerful military air deterrent. These achievements were the result of outstanding improvements in aerodynamics, engine technology, and metallurgy. Improved metals played a vital role in the application of the jet principle to aviation. Without metals capable of withstanding the high temperatures generated by the **gas turbine engine,** the dream of jet-propelled flight would not have become a reality.

In less than 70 years since the Wright brothers made their first sustained flight, aerospace vehicles have become so complex that only highly trained engineers can design and build them. The Wright brothers and their contemporaries could design and build an airplane in a matter of weeks. The development period of modern air and space vehicles may take from four to eight years and five million engineering manhours. These machines are not only structurally complex; they also require intricate electronic equipment and thousands of ground support operations to fulfill their role.

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* A jet engine that uses a gas turbine to drive an air compressor.
** A turbojet engine that uses its turbine shaft to drive a propeller.

Aerodynamic and Structural Improvements

In the immediate postwar years, engineers faced a number of strange new problems as the speed of the airplane increased. For one thing, a pilot traveling at a high rate of speed could not manually control his aircraft. Engineers applied hydraulic power to control the airplane in air pressures created by speeds of 600 or more miles per hour. They installed special ejection seats that would explode a pilot into the air away from his aircraft when trouble developed. In addition to a pressurized cockpit, the large bomber required a refrigeration system to overcome the heat produced by fast-moving air over its outer surface. Automatic controls consisting of numerous buttons, dials, levers, and blinking lights required miles of electric wiring.

One of the surprising features of the jet airplane was its capacity to increase its speed. The faster it flew through the air, the easier it became to produce more thrust, and, as it flew higher, it needed less thrust to move at greater speeds. Engineers built jet engines that made 1,800 revolutions a minute and permitted speeds as high as 650 miles per hour. Then, as speeds increased beyond 650 miles per hour, a cone-shaped shock wave of compressed air built up on the leading edge of the fuselage. At speeds above 650 miles per hour at high altitudes, this wave gripped the rear control surfaces and often tore off the wings. Many planes literally exploded in the air, while others plummeted to the earth in nose dives. Since this phenomenon always occurred as the airplane approached the speed of sound, it became known as the **sonic barrier** (Fig. 62).

Engineers finally overcame this barrier with an experimental X–1 rocket plane shaped like a giant 50-caliber bullet. Although this plane withstood the sonic barrier and reached a speed of 900 miles per hour, they next added swept-back wings that pushed the shock wave off the wing tips. This permitted the airplane to glide through the sonic barrier rather than meet it head-on.

In a little more than 10 years after the end of World War II, jet bombers and fighters had become almost indistinguishable. With about

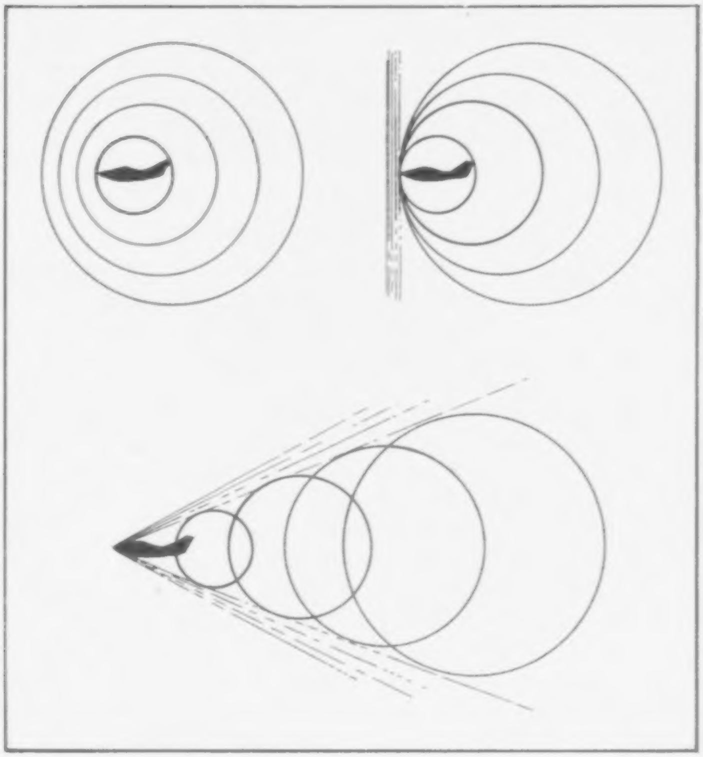

Figure 62. The sonic barrier is a shock wave of compressed air that builds up on the control surface of an aircraft. The key to the solution of sonic problems was to build thinner wings with sharp leading edges, make them shorter and wider, and sweep them back in the shape of a "V."

the same weight and operational ceilings, some bombers and fighters breezed through the air at supersonic speeds up to 2,000 miles per hour. Then came another problem accompanied by a significant innovation in the design of the airplane. At these exceedingly high speeds, a **boundary layer of air*** traveled with the airplane and raised the temperature of its outer metal surface to a dangerous level. At speeds of about 1,300 miles per hour, the temperature increased to 250 degrees, and, at speeds over 2,000 miles per hour, it jumped to 650 degrees, a level higher than the melting point of aluminum. Again, engineers came to the rescue, this time with a coating of flexible **titanium,** as light as aluminum but far stronger and more heat-resistant.

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* A thin layer of air next to an airfoil, distinguishable from the main airflow by distinctive flow characteristics of its own set up by friction.

Supersonic speeds of jet aircraft brought other structural, as well as aerodynamic, problems. For example, the stressed-skin structures of slower airplanes tended to buckle under the stress of high speeds, and smooth skin was vitally important at supersonic speeds. Strangely enough, the thin wings used on supersonic aircraft only added to the structural problem. The solution was to make the wings from thicker metal sheets, even though this increased overall weight. On the B–47, for example, wing thickness varied from 5/8 of an inch at the fuselage to 3/16 of an inch at the tip. Many designers began using "sandwich" materials on the main structure and control surfaces of jets, especially military aircraft. This is a honeycomb material made of thin stainless steel and ceramic which provides a light, smooth skin and, at the same time, protects the fuel from extreme temperatures.

The ever-increasing power of the jet engine was obviously a major contributing factor in these innovations. The pure gas jet turbine (turbojet) has steadily advanced in power and efficiency since the early Whittle and Ohain engines. The **turbofan engine** is perhaps the most significant innovation that has occurred thus far in the pure gas turbine jet. This engine applies not only Newton's third law of motion (exhaust gases) but also his second law which states that an acceleration of a given mass (air) produces a predictable force (bypass gases). The force can be increased either by increasing the speed of the air or by moving a larger volume. Although a turbofan or bypass engine expels exhaust gases at a slower speed than the turbojet, it exerts a greater thrust because some of the intake air speeded up by the turbofan bypasses the combustion chamber and accelerates as it leaves the engine. Thus, the turbofan provides a greater thrust with a lower fuel consumption. From the thrust range of 1,000 to 1,100 pounds of the Whittle and Ohain engines, the thrust ratings of turbojets have climbed as high as 40,000 pounds.

Paradoxically, the turbojet engine's great speed imposed certain limitations on its use. At high speeds, great quantities of air thrust into the intake ducts of a jet plane created increased "ram" pressure. This rapid compression produced dangerous increases in air temperature. For example, at mach 3, or three times the speed of sound, the air at stratospheric altitudes enters a jet engine at a temperature of about 635° F. At mach 4, the temperature doubles. The compressors in an

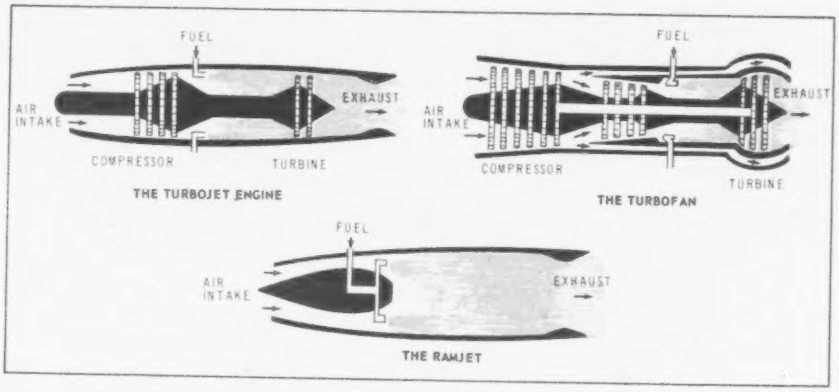

Figure 63. The jet engine increased in power when engineers designed the turbofan and ramjet engines.

ordinary turbojet engine further compress this heated air and raise the temperature even higher. By the time this air reached the combustion chamber, it became overheated and endangered the metal turbines that drove the compressors. With existing fuels and engine materials and speeds in the range of mach 3 or 4, engineers were impelled to create a new type of power plant. This problem led to the simplest and the most modern jet engine design yet known—the **ramjet** (Fig. 63).

Often described as a "stovepipe," the ramjet is the same as a turbojet, except that it has neither compressor nor turbine. Since the ram effect occurs only at high speeds, this engine does not operate efficiently at low speeds.

Since most of the early jet engines required about a pound of fuel to produce a pound of thrust for an hour, commercial airlines at first considered the turbojet too expensive for civilian transportation. This led to the development of a hybrid gas turbine or propeller turbine, better known as the **turboprop.** In this type of engine, a gas turbine drives a propeller which derives its thrust from the jet exhaust. Most commercial airliners used this engine until improvements in turbojet engines overcame the turboprop's economic advantages. One of the most powerful turboprop engines in service after the war powered the four-engine airliner, the Tupolev TU–114.

The rocket engine has been the subject of intensive research since World War II. This engine burns either solid or liquid fuel and can be used for jet-assisted takeoff, but it is used today primarily as a booster for missiles and spacecraft. The Redstone rocket that sent the first American into space delivered 75,000 pounds of thrust. The giant Saturn V booster that fired the Apollo spacecraft to the moon used five rockets in the first stage to produce 7,500,000 pounds of thrust.

Numerous other improvements in materials, methods of construction, and design gave the airplane an almost unlimited capability. It also became so complex that any attempt to compare it with the Wright brothers' *Flyer* borders on the ridiculous. One of the most obvious evidences of the airplane's growing complexity is the pilot's instrument panel. A modern jet pilot is almost completely surrounded by more than 150 dials and controls, ranging from an airspeed indicator to an automatic tracking and landing system. In fact, supersonic speeds created so many problems of control that computers eventually assumed part of the pilot's control responsibility. Even with these achievements, the air-breathing jet aircraft has by no means reached the peak of its development cycle. Aeronautical engineers tend to view mach 3 speeds much the same as World War I pilots viewed the first flight of the Wright brothers. They now talk in realistic terms of stratospheric aircraft operating at speeds that approach mach 25—roughly 16,500 miles per hour.

Military Aviation

Although jet propulsion brought revolutionary changes in the airplane, these changes did not have the same radical effects on the design of the airplane as the innovations of the 1930s. The major advantages of the jet engine stem from its capacity to power larger and faster airplanes than the piston engine. When the airplane flies at speeds above 450 miles per hour, the jet engine becomes increasingly more efficient than the combination of a piston engine and a propeller. In general, a modern jet engine develops about 10 times as much power from a single unit and weighs less in relation to the power it develops than a piston engine. Thus, the efficiency of the jet engine increases as its capacity to power larger and faster airplanes is exploited. In contrast to the engines used on airplanes in World War I, this feature makes the jet engine especially attractive for modern military use. It also explains why military aviation set the pace for rapid developments in jet propulsion following World War II.

During the 1930s, most of the innovations in airplane design appeared first on commercial airliners. The jet engine, on the other hand, had almost 10 years of military service before the commercial airlines accepted it for passenger transportation. Designers of the 1930s innovated primarily to make the commercial airliner more efficient. In the forties and fifties, they wondered whether the innovations brought by jet engines would make airliners less efficient.

The military made fantastic advances in the application of jet propulsion to fighter and bomber aircraft in the immediate postwar years. As the power of the jet engine increased, the missile introduced new concepts of warfare. Here was a combat weapon with its own propulsion system, navigational guidance, **homing devices,*** and an electronic brain sensitive to heat, light, and changes in the earth's magnetic field. It could perform the same mission as fighters and bombers at far greater speeds and did not require a human pilot. This development leads many people to believe that manned combat flying is obsolete. If this is true, it could mean the beginning and the end of the jet-propelled combat airplane before it plays a major role in warfare. Other sources believe that the manned combat aircraft will always play a complementary roll to the missile.

Although jet fighters saw service in the Korean War, the jet airplane was still something of a novelty. Early jet engines consumed too much fuel to be of practical use on large bombers and transport planes. They performed more efficiently on fighter aircraft where speed was more important than range. The most outstanding American jet fighters of this period were the F–80 *Shooting Star*, the Republic F–84 *Thunderjet*, North American F–86 *Sabre*, Lockheed F–94 *Starfire*, Republic F–84 *Thunderstreak*, and the Grumman F-9F *Cougar* (Fig. 64). These fighter planes attained speeds of 550 to 700 miles per hour.

Bomber aircraft advanced rapidly in the United States from propeller-driven to jet-propelled machines. The outstanding propeller-driven heavy bomber in 1946 was the six-engine Convair B–36 with a range of about 5,000 miles. A later model added four turbojet engines in two pods under the wing for takeoff and combat. It thus became the first bomber to make the transition to jet propulsion. The year 1947 marked the beginning of the modern jet-propelled bomber with the flights of such **prototype**** machines as the Convair XB–46, the Martin XB–48, and the large six-engine Boeing XB–47 *Stratojet*. These aircraft flew at speeds over 600 miles per hour.

The period from 1950 to 1960 saw both the jet fighter and the jet bomber reach supersonic speeds in a variety of types. The North

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* Devices incorporated in a guided missile or the like to home it on a target.

** The first complete and working member of a class, especially applied to the first aircraft made of a given model or model series, serving as the pattern or guide for subsequently produced members of the same class.

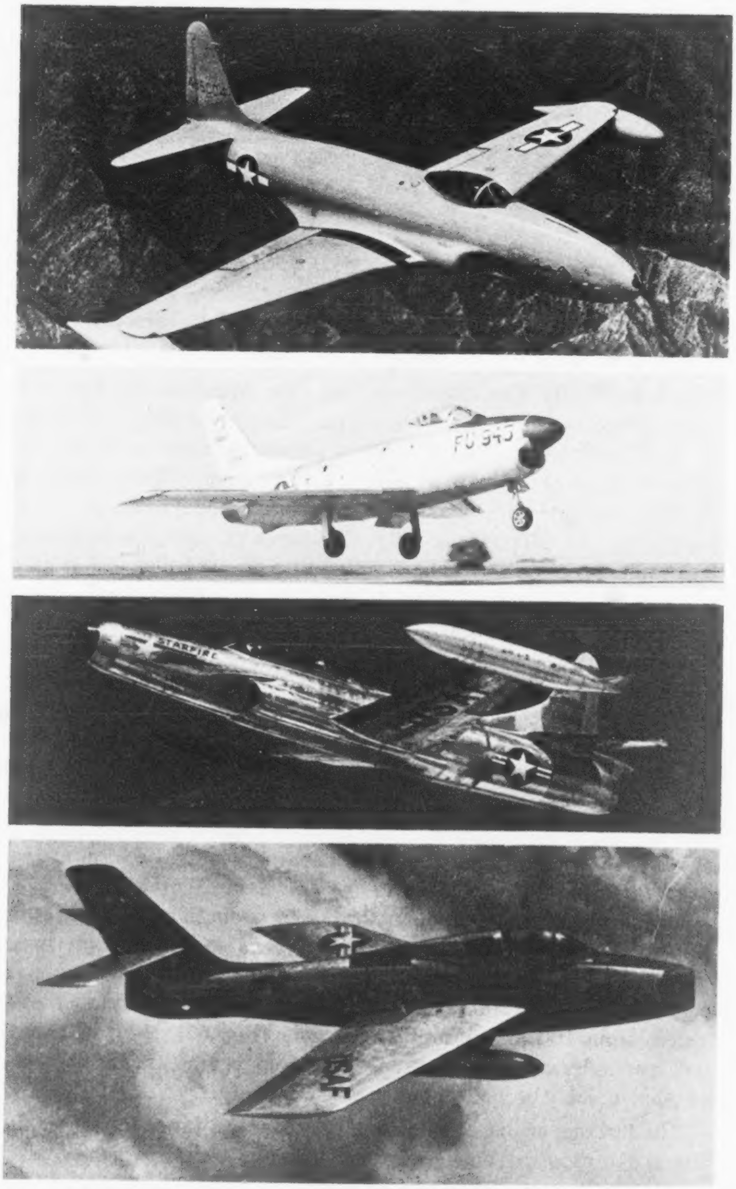


Figure 64. Outstanding early American jet fighters that saw service during the Korean War. F–80, F–86D, F–94C, and the F–84F.

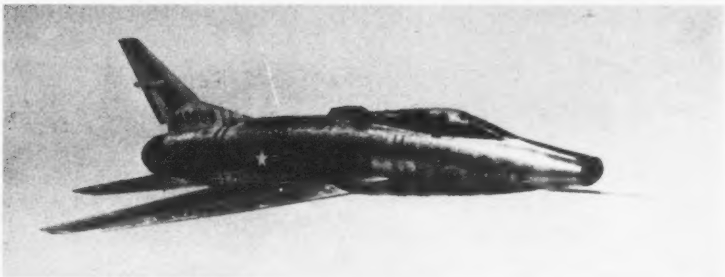
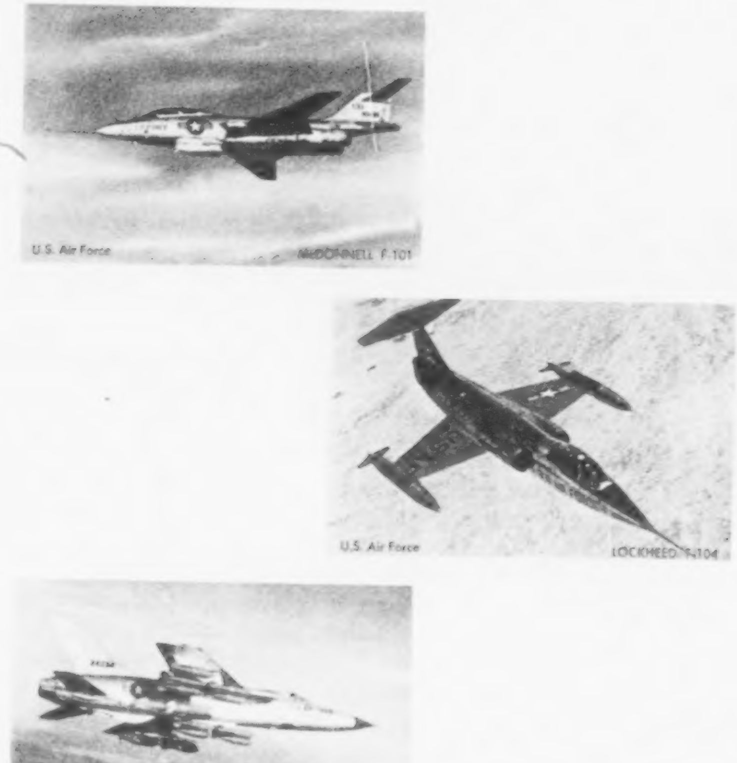


Figure 65. The F–100 Super Sabre was the first American jet fighter capable of sustained supersonic speeds.

American F–100 *Supersabre* was the first American jet fighter to enter service capable of sustained supersonic speeds (Fig. 65). A single J–57 turbojet engine with 10,000 pounds of thrust gave this airplane a speed of more than 800 miles per hour. Other supersonic fighters were the McDonald F–101 *Voodoo,* the Lockheed F–104 *Starfighter,* the Republic F–105 *Thunderchief,* and the McDonald F–4 *Phantom* (Fig. 66). The *Voodoo* flies at more than 1,200 miles per hour and can be used either as a rocket-carrying interceptor or as a reconnaissance plane capable of photographing ground activities at supersonic speeds from treetop level to an altitude of 45,000 feet. The *Starfighter* flies at speeds above 1,400 miles per hour (mach 2) and can climb to altitudes above 55,000 feet. Its armament includes *Sidewinder* infrared-guided missiles, rapid-fire cannon, and assorted bombloads. The *Thunderchief* is an all-weather fighter-bomber that also flies at mach 2 speeds and carries an awesome array of rockets, bombs, and guided missiles. The *Phantom* can streak through the air at speeds greater than 1,650 miles per hour and carries more than twice the explosives of a B–17 *Flying Fortress* in World War II.

One of the most revolutionary developments in fighter aircraft is the General Dynamics F–111, the first airplane to use **variable-sweep wings** that can be adjusted during flight. With two turbofan engines, each capable of 20,000 pounds of thrust, this versatile aircraft flies at speeds from 100 to 1,850 miles per hour (Fig. 67). With its takeoff and landing gear up and its wings swept back against the fuselage, this airplane quickly becomes a supersonic sky charger.

The turbojet engine enabled bombers to travel faster for longer distances and produced changes in design similar to those which occurred on modern fighters. The most noticeable were swept-back wings and



U.S. Air Force

McDONNELL F-101
LOCKHEED F-104
REPUBLIC F-105
McDONNELL F-4

Figure 66. Some modern supersonic fighters are the F–101 Voodoo, the F–104 Starfighter, the F–105 Thunderchief, and the F–4 Phantom.

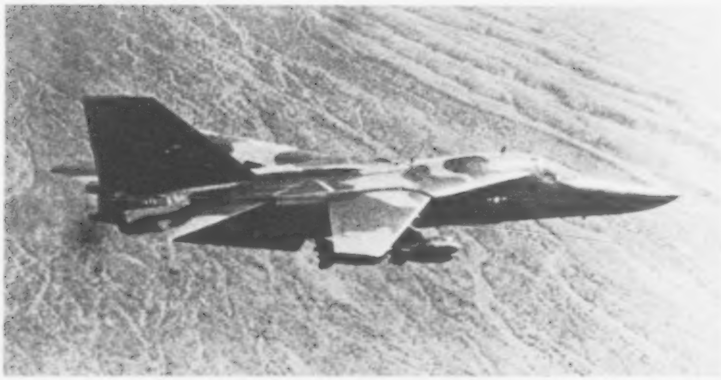


Figure 67. A camouflaged F–111 loaded with bombs.

engines suspended in small pods beneath the wings. One of the most outstanding American bombers was the Boeing B–52 *Stratofortress*, an intercontinental jet that reached a maximum speed just below the sonic range. Eight turbofan engines, each with 17,000 pounds of thrust, give this aircraft a range over 12,000 miles and an operating ceiling over 50,000 feet. It can carry 20,000 pounds of armament, including *Hound Dog*, jet-propelled air-to-ground missiles.

The first American supersonic bomber was the delta-wing Convair B–58 *Hustler* with four turbojet engines of 15,000 pounds thrust mounted in pods under the wing. It had a loaded weight of more than 160,000 pounds and a maximum speed of about 1,360 miles per hour at 35,000 feet. In May 1961, a *Hustler* flew a distance of 3,699 miles nonstop from New York to Paris in 3 hours and 20 minutes, the same route taken by Charles Lindbergh in 33 hours and 30 minutes (Fig. 68). The latest American bomber is the swing-wing FB–111, an enlarged version of the F–111 fighter aircraft.

Cargo and transport planes represent another category of military aircraft that developed rapidly during the postwar years. Beginning with the C–47, the military version of the DC–3, military cargo planes exploited the growing power of the aircraft engine to carry heavy loads as cheaply as possible over long distances. Some of the most outstanding military transports to enter service between 1945 and 1971 were the C–110 *Flying Boxcar*, C–124 *Globemaster*, C–130 *Hercules*, C–133 *Cargomaster*, KC–135 *Stratotanker*, C–141 *Starlifter*, and the C–5 *Galaxy* (Fig. 69). These airplanes and their design are discussed at length in *Aircraft of Today*.

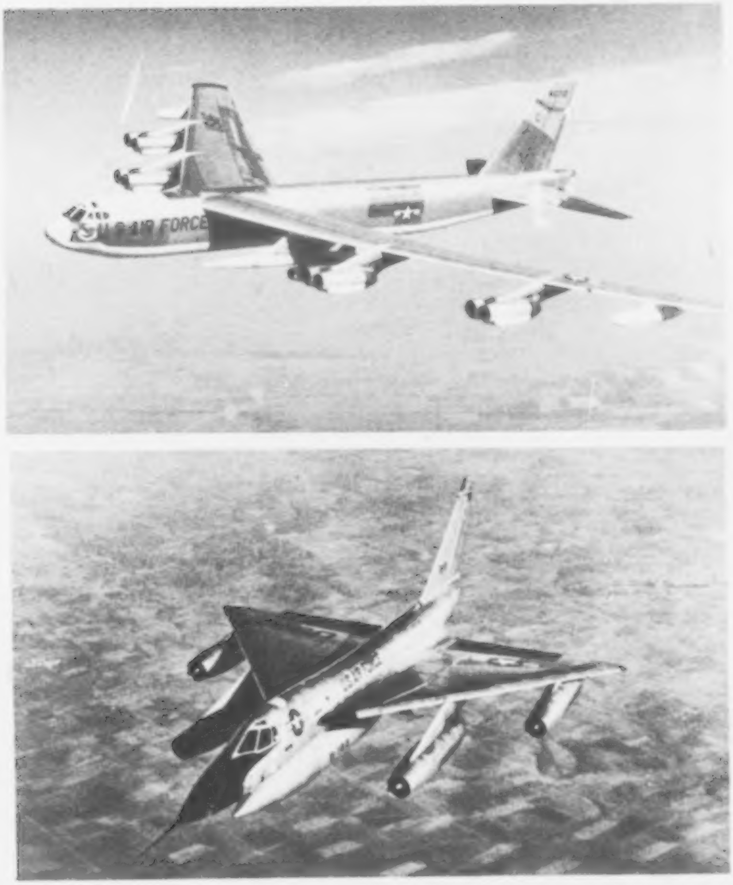


Figure 68. The B–52 Stratofortress is a subsonic American bomber with a range of more than 12,000 miles. In 1961, the B–58 Hustler flew nonstop from New York to Paris in 3 hours and 20 minutes.

Commercial Aviation

For most people, the commercial airliner is the most obvious example of the progress brought by the aerospace revolution. In a relatively short period of time, the passenger-carrying airplane has become a flying palace with all the conveniences of a modern hotel or country club. Today, a traveler on a jet airliner rests in almost total comfort seven miles above the earth and crosses the United States nonstop in

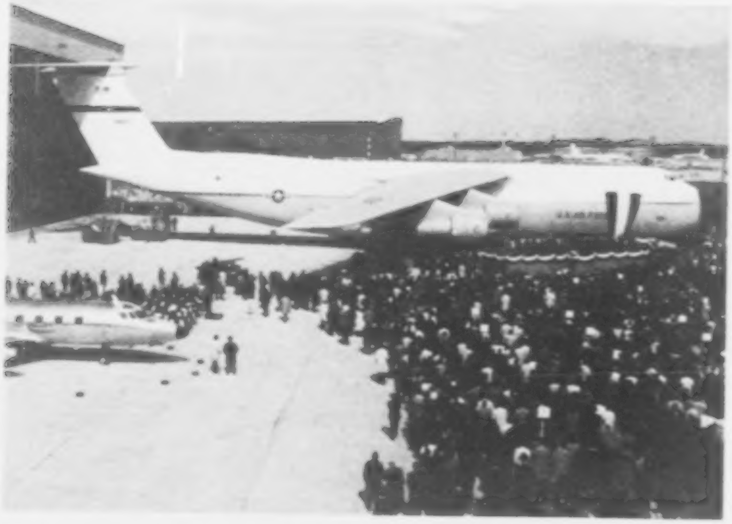


Figure 69. The C-5 Galaxy on display at the Lockheed plant in Marietta, Georgia.

six hours or less. During his trip, he can leisurely sip a cup of coffee or enjoy a seven-course dinner prepared by skilled chefs. In plush, reclining seats, he can relax to the strains of stereophonic music or watch a sports feature on color television. He travels in the company of hundreds of other people who share his flight with him. Time passes so swiftly that only the soft jolt signalling arrival at his destination reminds him that he is not dreaming.

A little more than 40 years ago, a passenger on a transcontinental airline donned a flying suit, helmet, goggles, and a parachute before he boarded his plane. He entered the airplane through a door just large enough for his body to pass through. During the flight of 32½ hours and 16 or more stops, he either did without food or ate a light, packaged lunch. He endured the smell of aviation fuel, the roar and vibrations of the propellers, and a crowded passenger compartment which he shared with a pile of mail bags. If he traveled westward from the east coast, he probably heaved a sigh of relief after his plane passed over the Allegheny Mountains.

Today, an airline passenger flies across the Atlantic Ocean on a huge jetliner in about six hours. Forty years ago, there were no transoceanic flights. A single commercial airliner on one transcontinental flight can carry more people than made the same trip during the entire first year that transcontinental air service was available. One airline alone can transport as many as 12,500 passengers across the United States every day. Airports in large cities, such as New York, Chicago, or Los Angeles, handle a landing and takeoff every 50 seconds. In a single year, more than 9,000 commercial airline planes transport over 100 million passengers to points in the United States and every part of the world. These developments have occurred, for the most part, in the period between the end of World War II and the present, a period which saw the airliner enter the jet age.

For almost 10 years following World War II, American-built airliners dominated the world airline market. The most outstanding airliners of this period were the Douglas DC–6 and 7 series, the Boeing 377 *Stratocruiser*, the Lockheed *Constellation*, and the *Super Constellation* (Fig. 70). The DC–6 appeared in 1946 with four engines that provided a total of 8,400 horsepower. This airplane carried 48 to 58 passengers at 20,000 feet in a pressurized cabin that maintained the equivalent of a 5,000 foot altitude. It had a speed of 300 miles per hour, a range of 2,600 miles, and a payload of 14,000 pounds. A modified DC–6B served as a 32-passenger sleeper aircraft and flew the transpolar route from the west coast to Europe. A 101-passenger version made the transcontinental run from the west coast to New York. The Boeing 377 *Stratocruiser* was a double-deck, four-engine aircraft based on the design of the B–29 bomber. With its 2,800-horsepower

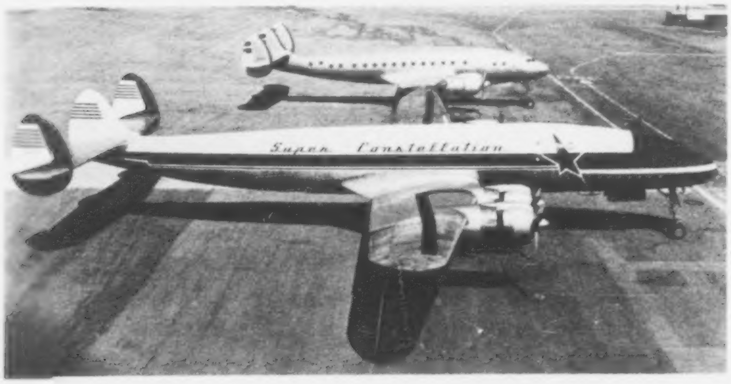


Figure 70. The Lockheed Super Constellation was one of several outstanding commercial airliners in the decade following World War II. Others were the Douglas DC–6 and –7 series, the Boeing 377 Stratocruiser, and the Lockheed Constellation.

engines, it cruised at 340 miles per hour, reached altitudes of 25,000 feet, and had a range of 4,600 miles. The Lockheed *Constellation* and *Super Constellation* were triple-tailed aircraft that made transoceanic flights with ease. Four 2,500 horsepower engines enabled the *Constellation* to cruise at 328 miles per hour with 44 to 64 passengers. The *Super Constellation* carried four 3,250-horsepower engines and cruised at a speed of 355 miles per hour with as many as 99 passengers.

In 1953, the DC–7 appeared with four turbo-compound engines that provided 3,350 horsepower. Again, the airplane's range, payload, and speed increased to the point that trunk airlines now were able to fly realistic transcontinental nonstop schedules for the first time with as many as 95 passengers. The DC–7B went into service in 1955, followed a year later by the DC–7C which had 10 additional feet of wingspan to carry fuel for transoceanic flights. Known as the "Seven Seas," this luxurious aircraft carried a payload of 122,200 pounds at speeds up to 410 miles per hour. This airplane was the last of the piston-engine DC transports, an outstanding series that had dominated air travel for more than 20 years.

Practical jet propulsion introduced a technological breakthrough that had the most revolutionary effect on commercial air travel since the DC–3. The first jet airliner to enter commercial service was the British de Havilland *Comet* in 1952. This airplane carried 45 passengers at an altitude of 42,000 feet and a speed of 490 miles per hour. For almost two years, the *Comet* established world records as the only jet airliner in service, but, after a series of disasters, its prestige diminished. American companies sketched blueprints of jet airliners in the 1940s and early 1950s but hesitated to invest in pure jet aircraft production. They compromised by introducing the first turboprop airliner used in the United States, the British Vickers *Viscount*. The foremost American turboprop aircraft was the four-engine Lockheed *Electra*, which carried 85 passengers at a cruising speed of 405 miles per hour. It was quickly outdated, however, with the introduction in 1958 of the Boeing 707, the first pure jet airliner to enter commercial service in the United States (Fig. 71). It is interesting to note that these things occurred after the Soviet Union launched its first Sputnik satellite.

The first version of the 707 carried 189 passengers at speeds of more than 600 miles per hour at 25,000 feet. Subsequent models of this airliner rapidly became dominant types on the commercial jet market. The present Boeing 707–320B *Intercontinental* carries four

Figure 71. The Boeing 707 was the first pure jet airliner to enter commercial service in the United States.

turbofan engines, each capable of producing 18,000 pounds of thrust. The basic 707 design also served as the design for a series of medium- and short-range jet airliners, such as the 727 and 737 series. The medium-range 727 cruises at a speed of 600 miles per hour for distances up to 2,000 miles and serves either as a cargo-passenger airliner or as a complete air freighter. As a freighter, it can carry a total weight of 36,750 pounds. The 737 is a short-range aircraft with wing-mounted engines capable of carrying passengers and baggage for distances up to 1,840 miles. It also serves as a combination cargo-passenger airliner or as an all-cargo carrier.

Figure 72. The McDonnell-Douglas DC-9 is a short- to medium-range jetliner that serves hundreds of communities previously served only by propeller-driven aircraft.

The first jet airliner produced by the McDonnell-Douglas Company was the DC–8, which appeared in mid-1959. The design of this aircraft set the pattern for a series of DC–8 *Super 60* transports that cruised at a speed of 600 miles per hour at altitudes between 35,000 and 40,000 feet. The DC–8 *Super 61* carries more powerful engines and is 37 feet longer than the *Super 60*. Both planes have cruising speeds of about 600 miles per hour over transcontinental ranges. The shorter-range DC–9 travels at a speed of about 565 miles per hour for distances up to 1,000 miles (Fig. 72).

Another revolutionary development in civil air transportation came with the introduction of the so-called "jumbo jet," which requires space larger than a football field to turn around. From the standpoint of technology, the jumbo jet does not present any radical improvement over smaller jet airliners. It qualifies as a significant achievement in aviation history by virtue of its immense size. It does not compare with the technological triumph represented by the first jet commercial airliner, nor will it compare technically with the supersonic transports of the future.

The Boeing 747 jetliner is only slightly smaller than the Air Force C–5 and is the largest airplane ever built entirely for commercial service (Fig. 73). The pilot in this giant of the airways sits 30 feet above the runway. Behind him, the vertical stabilizer rises 63 feet into the air—higher than an average five-story building. Its four turbofan en-

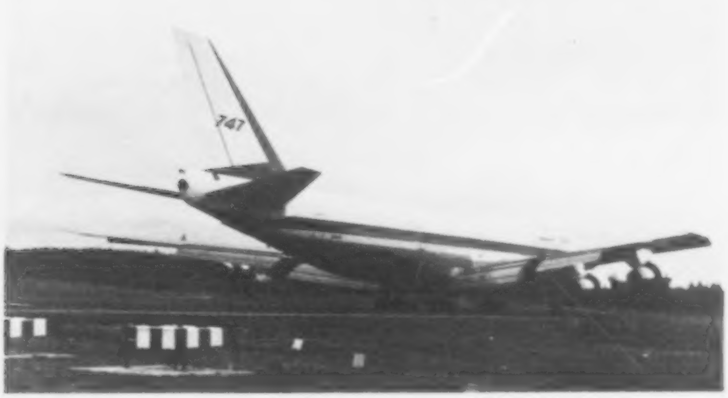


Figure 73. The Boeing 747 is the largest airplane ever built entirely for commercial service

gines give it twice the thrust of any other commercial airliner. Despite its mammoth size, the 747 flies at speeds up to 625 miles per hour at an altitude of 40,000 feet over a range of 6,000 miles. It has a 16-wheel main landing gear as compared to the 8-wheel gear of the 707. It performs at one-fourth to one-third lower operating cost than the 707.

Passengers enter this aircraft through five double-width doors on each side of the fuselage. Instead of a tube-like structure found in smaller aircraft, the cabin of the 747 is a large, elegantly appointed room with clever lighting effects that add to the impression of roominess. A spiral staircase leads to an upstairs lounge, observation deck, and movie theater, more closely resembling the design of an ocean liner than an airplane. It is the ultimate in modern air transportation.

Other marvels of the Aerospace Age are the freighter versions of the jumbo jet. The 747F, for example, carries over 100 tons of freight as compared with the capacity of the 707 to carry 45 tons. The entire nose of this huge airplane opens beneath the cockpit, providing an opening more than 10 feet wide and 8 feet high. An automated loading system built into the floor makes it possible to position each container or pallet with a minimum of human effort. A direct descendant of the Air Force C–5 is the Lockheed L–500–114 jet freighter, which is even larger and heavier than the 747F. Both the 747 and the L–500 use high bypass ratio turbofan engines capable of generating as much as 45,500 pounds of thrust at takeoff.

Although these and a number of other American airliners dominate the world commercial market, Great Britain, France, and the Soviet Union also produce outstanding commercial airliners. The most notable are the British BAC–111, the French Caravelle series, and the Soviet Tupolev TU–114. *Aircraft of Today* includes a more detailed discussion of these aircraft and their relative position in modern aviation.

At this writing, the airplane appears on the verge of taking another major step forward in the form of the supersonic transport (SST). Although the United States has not yet produced an SST, Great Britain, France, and the Soviet Union have already concluded flight tests with aircraft capable of supersonic speeds above mach 2. Both the Concorde and the Tupolev TU–144 fly at speeds that will revolutionize air travel as it is currently understood. Speed, of course, is a primary characteristic of modern air transportation, but it is not the airplane's only achievement. Already in operation are vertical takeoff aircraft that will provide rapid and reliable local contacts with long-distance supersonic flights.

As fantastic as are modern aviation achievements, however, the development of the modern commercial airliner is probably only in the beginning stages. Even the supersonic airliner of tomorrow may eventually be outdated by a rocket-powered craft that will reduce travel time between continents to a matter of minutes. Some people envision a time when earth men will travel by commercial transport to visit their distant neighbors in space. Today, the passenger who streaks from continent to continent in six hours may be traveling on a mode of transportation as far from the future as the Boeing 747 is from the Wright brothers' *Flyer*.

The Space Age: A Beginning

For almost 2,000 years, man dreamed of traveling through space to other worlds beyond the earth. He used rockets in war for almost 600 years before he linked the principle of rocketry to his dreams of spaceflight. Not until the late nineteenth century did he recognize the rocket as the key to his dreams of spaceflight. Even then, long years of research and experimentation were necessary before manned flights in space became a reality. Like its predecessors, the modern rocket developed as the practical answer to a military need. Such men as Tsiolkovsky, Goddard, and Oberth considered the rocket primarily as a vehicle for achieving spaceflight. Out of their experiments came the technical knowledge used by the Germans in World War II to produce the V–1 and V–2 guided missiles. The United States, the Soviet Union, Great Britain, and Japan used rockets and missiles of various sizes during the war. But it was the work of German scientists and engineers at Peenemunde that brought rapid postwar advances in rocket technology. The V–2 is the direct ancestor of all major postwar developments in military missiles and space carrier vehicles.

Advanced rocketry and nuclear weapons developed since World War II have completely revolutionized concepts of war. Rockets led inevitably to the creation of missiles for use as military weapons. Today, intercontinental missiles armed with thermonuclear warheads are capable of destroying the vital centers of any nation on the earth. Events leading to these missiles took place primarily in the United States and the Soviet Union.

The Air Force first entered the long-distance missile field in 1944 with the launching of a JB jet-propelled guided bomb series modelled after the German V–1 and based on information obtained during World War II (Fig. 74). These were subsonic winged missiles that

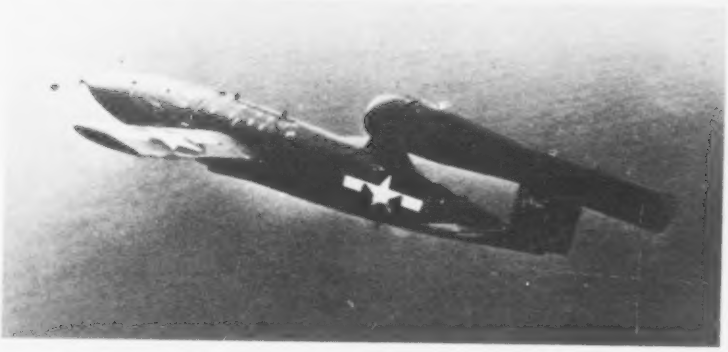


Figure 74. The Air Force modelled its JB flying bomb series after the German V–1 that flew over London in World War II.

flew at slow cruising speeds and offered relatively easy targets. Following the JB experiments, the Air Force developed two other subsonic missiles called the *Snark* and the *Matador*. The *Snark* had an intercontinental range of 5,000 to 7,000 miles and carried a 5,000-pound nuclear payload. It entered service with the Strategic Air Command in 1958 but was phased out as the supersonic *Atlas* missile became operational. The *Matador* was a smaller, short-range missile that later became the faster, more accurate *Mace*, which was deployed in Europe and the Far East during the early 1960s.

The next step in the evolution of American intercontinental ballistic missiles came in the mid-1950s with the development of the *Navaho*, a 300,000 pound missile equipped with an **all-inertial guidance system**.* Powered by three liquid-propellant rocket engines of 135,000 pounds thrust each, this vehicle flew at three times the speed of sound. Although the *Navaho* program was cancelled in 1957, it provided the technological basis for later ICBMs (Fig. 75). Not only were updated versions of its powerful engines applied to such missiles as the *Jupiter*, *Thor*, and *Atlas*. It also solved many problems regarding the flight and design of large supersonic vehicles. Experience gained from this program later proved helpful in the development of the air-launched *Hound Dog* missile, the *Minuteman ICBM*, and such high-speed airplane programs as the XB–70 and the X–15.

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* A kind of guidance for a missile or the like, effected by means of mechanisms that automatically adjust the missile after launching to follow a given flight path, the mechanisms measuring inertial forces during periods of acceleration, integrating the data obtained with already-known position and velocity, then signaling the controls to affect the desired direction, altitude, etc.

In addition to the pioneering efforts of the Air Force, further developments in ballistic missilery came when German scientists, headed by Wernher von Braun, elected to continue rocket research at Fort Bliss, Texas. While these scientists continued their work in the United States, other members of the Peenemunde group worked on similar projects in the Soviet Union. In coordination with Army Ordnance, von Braun's assignment was to establish a ballistic missile program based on the V–2 used during World War II. This program marked the beginning of wide-ranging experiments which became known as the **Hermes program.**

Following a series of static firing tests, the V–2 made its first flight in the United States from the White Sands Proving Ground, New Mexico, in April 1946. The V–2 achieved its longest flight of 111.1 miles in December 1946 and its highest altitude of 132 miles in August 1951. These early V–2 flights gave American engineers valuable experience in launching large vehicles and furnished important information about the upper atmosphere (Fig. 76).

In a program called **Operation Bumper,** the Army used a small American WAC Corporal rocket as a second stage of a V–2 to reach higher altitudes. One Bumper flight in 1949 reached an altitude of 244 miles and a top speed of 5,150 miles per hour. These flights estab-

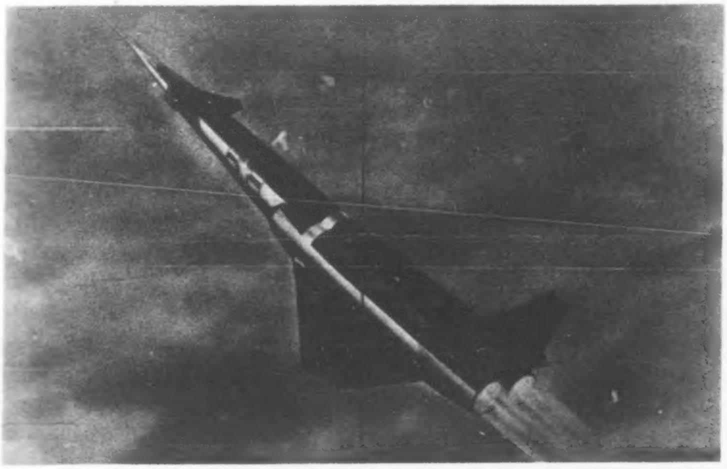

Figure 75. The Navaho was a 300,000-pound liquid-propelled missile that provided the technological basis for American intercontinental ballistic missiles.

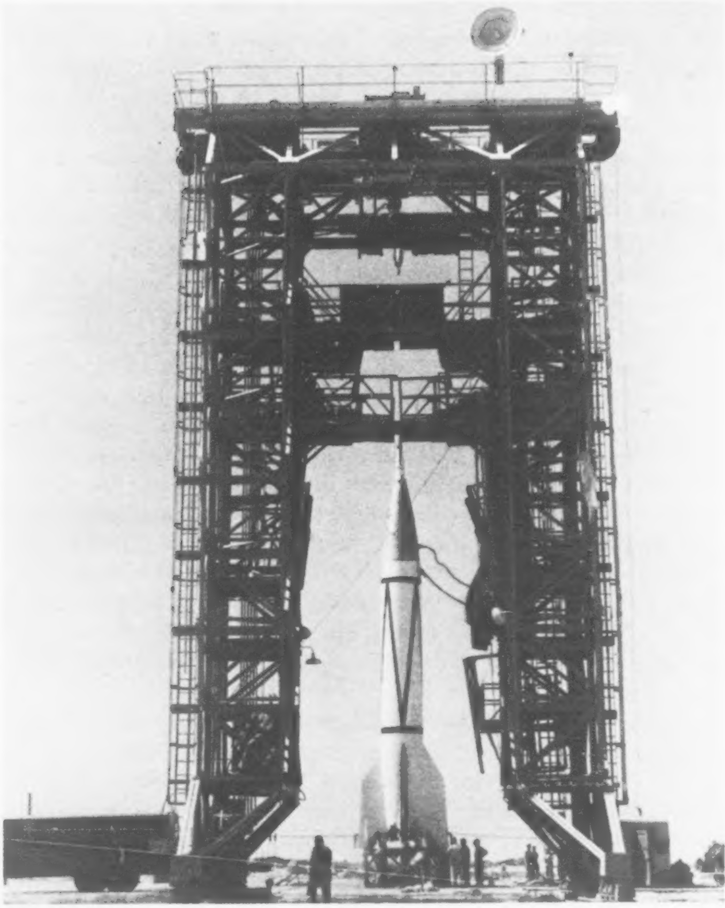

Figure 76. An American adapted V–2 in launch position at the White Sands Proving Grounds, New Mexico.

lished the techniques for firing two-stage missiles—ignition and separation at high altitudes and stability at high speeds.

The V–2 firings were only a part of the total Hermes program for advancing the art of rocketry. A Hermes A–1 rocket reached an altitude of 15 miles, a range of 38 miles, and a speed of 1,850 miles per hour. Changing requirements forced the cancellation of an A–2 rocket equipped with a solid-fuel motor. Though not eminently successful, other models of the A–rocket family, the A–3A and the A–3B, led to the development of a stable platform, a radio inertial guidance system, and engines with thrusts ranging from 18,000 to 22,600 pounds. Another rocket under study was the Hermes C, a three-stage missile that weighed 250,000 pounds and carried engines with 100,000 pounds of thrust. This missile led directly to the **Redstone** missile, the first major American effort in the ICBM field.

So rapidly had the US missile program developed by the late 1940s that it needed more space than was available at the White Sands Proving Ground. Following a long search, a team of almost 1,000 military personnel, scientists, and civilian employees moved to Redstone Arsenal at Huntsville, Alabama, where they would write a whole new chapter in rocket history. No sooner had they settled at their new location when the Korean War broke out in June 1950. Their first assignment was to design a 500-mile ballistic surface-to-surface missile. This missile's priority increased as the Korean War grew in intensity. First known as *Ursa* and then *Major,* it finally became known as the *Redstone,* a short-range missile that could be used by combat troops under battlefield conditions. With the addition of two special stages, it became the *Jupiter,* the first successful intermediate range ballistic missile developed in the United States (Fig. 77).

The *Redstone* and the *Jupiter* missiles set the stage for all subsequent developments in the United States missile program. Such names as *Polaris, Atlas, Thor, Titan, Minuteman, Nike, Sam, Sprint,* and *Nike-Zeus* represent an entire arsenal of short-, medium-, and long-range missiles that can carry warheads to any point on the earth. Fortunately for mankind, the same rockets that can propel these missiles from continent to continent can also lift vehicles into the upper atmosphere and outer space. Despite its use as a military weapon, the rocket has also furnished the power for man's most magnificent peacetime achievements—the exploration of space and manned landings on the moon.

Before reaching the moon, however, man had to learn more about the nature of space and the hazards that would confront him in the

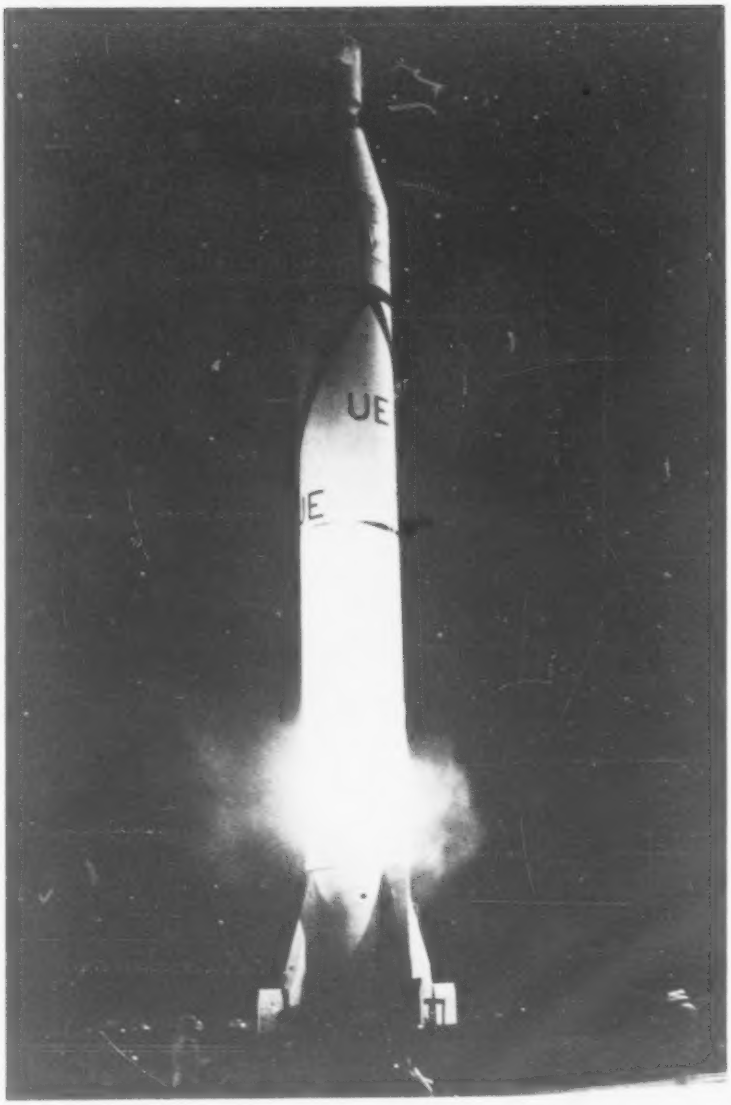

Figure 77. The Jupiter was the first successful intermediate range ballistic missile flown in the United States. On its first flight, it reached an altitude of 682 miles and landed 3,400 miles from Cape Kennedy, Florida. Two years passed before another American missile equalled this record.

space environment. For this study, the rocket served two purposes—to take measurements within the earth's atmosphere and to launch scientific payloads into orbit around the earth or to other planets. Scientists used sounding rockets for more than a decade before they launched space carrier vehicles. These rockets provided vital information on the temperature, density, and composition of the atmosphere from several miles above the earth's surface to the fringes of outer space. They measured radiation and its effects on the atmosphere, communications at high altitudes, and the types of cloud cover at given points on the earth. The *Viking* was the largest sounding rocket created in the United States. Others, including the *Aerobee* series, were the *Hawk, Nike-Apache, Nike-Cajun,* and *Wasp,* each with a different design and capability.

One of the significant dates in space history is 4 October 1957, the day that the Soviet Union introduced the age of space with the launching of *Sputnik 1,* the world's first artificial **satellite.** Its mission was to study the density and temperature of the upper atmosphere and measure concentration of electrons in the ionosphere. For more than a year, it circled the earth every one and one-half hours in an **elliptical orbit** ranging from 140 to 560 miles. Quickly on the heels of this event came *Sputnik 2,* weighing 120 pounds and carrying a dog, life-support equipment, instruments to measure the dog's reaction, and other equipment. Six months later, the Russians launched an even larger *Sputnik 3.*

The United States launched its first orbiting satellite, *Explorer 1,* on 31 January 1958, and followed it with *Explorer 2* in March 1958. Though not as large as the Sputniks, these satellites carried miniaturized instruments that gathered vital scientific information, including discovery of the Van Allen radiation belt (Fig. 78). Both the United States and the Soviet Union followed these initial achievements with the launching of numerous satellites to gather information about the moon, planets, and the space environment. Throughout the late fifties and early sixties, the United States achieved outstanding successes with a series of meteorological and communications satellites that gave a new dimension to weather forecasting and world communications systems. By 1966, *Tiros* and *Nimbus* satellites had relayed more than 100,000 pictures of cloud systems, while such communications satellites as *Echo, Telstar, Relay, Syncom,* and others made live television pictures available to world audiences. During the same period, the Soviet Union launched more than 100 *Kosmos* satellites and two huge *Proton* satellites that weighed over 26,000 pounds.

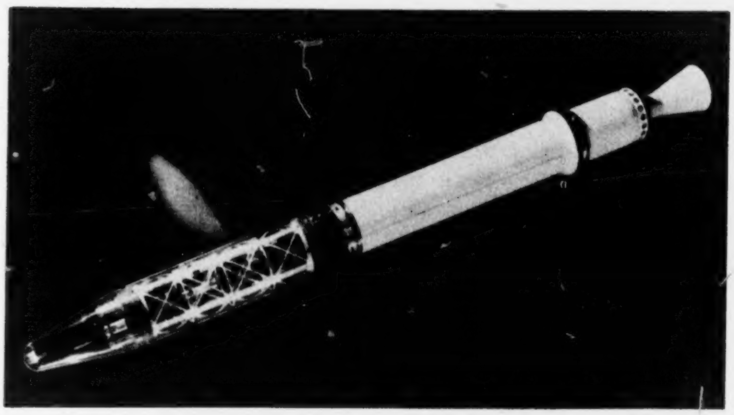

Figure 78. Explorer 1 was the first American satellite. It confirmed the existence of the Van Allen radiation belt surrounding the earth.

These events were only the beginning in a series of fantastic ventures that saw man-made satellites transmitting pictures and scientific data millions of miles through space to the earth. With more powerful rocket engines, **radio telemetry,*** and sophisticated guidance systems, both the United States and the Soviet Union extended their space probes to the moon and the planets of the solar system. These probes were the initial stages in the fulfillment of man's oldest dream—interplanetary travel. Since the moon is the closest member of the solar system to the earth, it was the logical first target. Again, the Soviet Union scored a first in 1959, with the firing of three *Luna* spacecraft. On 2 January 1959, *Luna 1* flew within 4,600 miles of the moon's surface and transmitted for the first time vital information about the moon. Also in 1959, an American spacecraft sent valuable information about the moon.

Following a series of dismal failures with six *Ranger* spacecraft from 1962 to 1964, the United States scored outstanding successes with *Rangers* 7, 8, and 9, when they relayed more than 11,000 pictures showing moon craters only a few feet across. Millions of Americans were thrilled with live television pictures of the moon broadcast by *Ranger 9* on commercial television sets. The *Ranger* missions were followed by the flights of *Surveyor* spacecraft designed to land on the moon and study the composition of the lunar surface. As a prelude to the Apollo flights, a *Lunar Orbiter* circled the moon at an altitude of about 28 miles and relayed pictures of objects from one to nine yards in size.

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* The practical art of using an electronic instrument that senses and measures a quantity, as that of speed, temperature, etc., and then transmits radio signals to a distant station where they are interpreted by code.

In addition to these moon probes, the United States scored spectacular successes with probes to the planets Venus and Mars. A series of *Pioneer* and *Mariner* spacecraft soared millions of miles through space and relayed pictures to the earth, showing detailed characteristics of the Martian and Venusian surfaces. US interplanetary flights began in 1960 with the launching of *Pioneer 5* toward Venus. Scientists tracked this spacecraft 22.5 million miles and received pictures from as far as 17.7 million miles from the earth. A *Mariner 2* spacecraft launched in 1962 flew within 22,000 miles of Venus and relayed data showing that Venus has a temperature over 700° F. and an unbroken cloud cover. A *Mariner 4* spacecraft launched in July 1965 flew within 6,118 miles of Mars after making a looping journey of 325 million miles in 7½ months. Pictures of Mars showed a pockmarked surface more like the moon than the earth.

These dramatic achievements show how rapidly the science of rocketry has advanced since the launching of *Sputnik 1*. During the years immediately following World War II, major developments in rocketry came as the result of a military need. But it was the requirement for increased payloads in space research that brought the most significant increases in rocket thrust values. Today, liquid-propellant rocket engines produce over 1,500,000 pounds of thrust in a single thrust chamber and more than 7,500,000 pounds in a clustered system of five engines. Operational solid-fuel motors 120 inches in diameter produced more than 1,200,000 pounds of thrust, and ground tests of larger units up to 260 inches diameter have produced up to 3,500,000 pounds of thrust. These are the engines that provide the power for manned spaceflights.

From relatively small V–2 rockets, to ballistic missiles, to sounding rockets, to unmanned spacecraft, the rocket has advanced in power to the point that it can boost not one man but three into orbit around the moon. Manned spaceflight in the United States began with the organization of Project Mercury in 1958 and continued through a period of about 12 years with the Gemini experiments and finally the Apollo moon landings. In the Mercury experiments, man proved that high-gravity forces at launch, atmospheric re-entry, and weightlessness in space would not impair his ability to control an orbiting spacecraft and

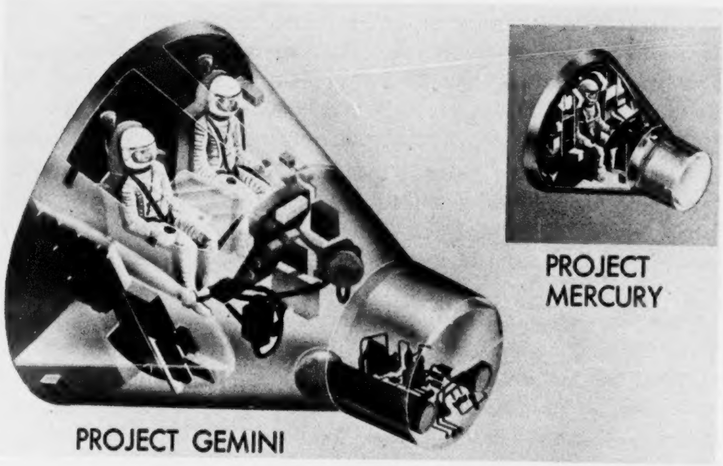

Figure 79. The Mercury and Gemini experiments proved that men could survive and perform normal functions under the weightless conditions of the space environment.

conduct experiments in the space environment. The Gemini experiments consisted of longer missions in space designed to test man's endurance under weightless conditions and to determine whether man could perform activities that would be necessary in lunar or interplanetary flights (Fig. 79). The Mercury flights used an *Atlas* rocket engine that developed 390,000 pounds of thrust at liftoff, while the Gemini flights used a *Titan II* launch vehicle that produced 530,000 pounds.

The Apollo project has been the biggest and most complex manned spaceflight experiment conducted by the United States. Its goal was to land American astronauts on the moon and return them safely to the earth. The Apollo 11 spacecraft accomplished this goal on 16 July through 24 July 1969. In contrast to the Mercury and Gemini spacecraft, the Apollo vehicle consists essentially of three spacecraft in one—the command module, the service module, and the lunar module. Like the crew compartment of a modern airliner, the command module contains windows, controls, and instruments, including a computer, for the astronauts to pilot the spacecraft. It is 11 feet long and 13 feet in diameter at the base. The service module contains rocket engines and fuel supplies for the astronauts to propel their craft into and out of lunar orbit and to change their course in space. It is 23 feet long and 13 feet in diameter. The lunar module is a ferry craft that transfers the astronauts from the spacecraft to the moon's surface and returns them to lunar orbit and rendezvous with the command and service module. It is about 20 feet high and 13 feet in diameter at the base. With the Saturn V launch vehicle, the entire Apollo assembly towers about 365 feet into the air (a distance greater than the length of a football field).

The Saturn V launch vehicle (See Fig. 7) contains one of the most powerful combinations of rocket power ever conceived by man. This giant weighs almost as much as a nuclear submarine (about 6 million pounds) and operates in three different stages to boost an Apollo spacecraft into orbit. At liftoff, the first stage burns over 15 tons of propellants per second and generates about 7.5 million pounds of thrust, a power equivalent of some 600,000 automobile engines. In two and one-half minutes of operation, it takes the Apollo to an altitude of about 36 miles and a speed of 6,000 miles per hour. The second stage consumes more than one ton of propellants per second and boosts the spacecraft to an altitude of about 108 miles and a speed near orbital velocity (about 17,400 miles per hour). After the second stage drops away, the third stage first places the spacecraft into a desired earth orbit and then boosts its speed to an escape velocity of about 24,900 miles per hour.

Spacecraft and Their Boosters contains a detailed discussion of American achievements in the exploration of space. They are included here only to show how man in a short period of about 70 years advanced in technology from Goddard's early rocket and the Wright *Flyer* to the *Apollo*. From a simple gasoline motor of about 12 horsepower and a rocket that flew for 2 minutes, he advanced to an age when horsepower is an unrealistic reference to the power placed in his hands by the rocket. And if he plans more advanced missions to other planets, the rocket no doubt will provide him with even greater power. Such missions will bring a requirement for new launch vehicles with many times the basic thrust of the mammoth Saturn V.

THE FUTURE OF AEROSPACE

In view of the rapid rates of change brought by advances in science and technology, forecast of future aerospace developments today may be reality tomorrow. So rapid and extensive have been technological advancements since 1900 that one dramatic change no sooner becomes established before it is superseded by another. For this, if for no other reason, long-range predictions of future developments in aerospace are uncertain. By the same token, vastly increased sources of engine and propulsive power since the Wright brothers have opened whole new horizons for manned flight. Given sufficient time and money, modern scientists recognize no absolute barriers to almost any type of flight. In the course of a single lifetime, man has advanced from his first powered flight of 30 miles per hour to more than 4,000 miles per hour in the X–15 and above 24,000 miles per hour in the Apollo spacecraft. An obvious conclusion is that the ultimate possibilities of flight have only begun to reveal themselves.

Winged Flight

With such aircraft as the X–15, the C–5 *Galaxy,* and the Boeing 747 already in operation, man's achievements in atmospheric flight can be matched only by his plans for the near future. The decade of the seventies will see a whole new breed of aircraft in operation.

For short- and medium-range flights, vastly improved subsonic airliners are already replacing conventional propeller-driven airliners. Refinements in the design and efficiency of turbojet propulsion systems now make it possible to build relatively "small" jets that may carry as many as 100 passengers. This family of jets will cover short hops of 200 to 1,000 miles in a period of one hour or less. Gen Bernard Schriever, a former commander of the Air Force Systems Command, describes civil air transport of the future in these words:

> Commercial air transportation will benefit from the military example and experience. In ten or twenty years, the big passenger market will be in low-cost, 500 miles-per-hour air travel. The business man will use the faster supersonic transport where time commands the premium, while the subsonic transport will offer the average traveler fast, convenient service at prices one-third to one-half of those today. Population and industrial centers will gravitate to locations made convenient by air transportation. . . . The air terminal of the future may become the center of a transportation network which will provide fast, efficient flow of goods and people. . . . Just as our past and present great cities have been major seaports, riverports, railway centers and highway centers—future generations will know great cities as major airports.

Modern engineers foresee a time in the not too distant future when people will travel from city to city on a new generation of **vertical flight aircraft.** Such a plane will take off and land vertically (VTOL) like the helicopter, fly at a speed similar to that of a propeller-driven aircraft, and carry as many as 100 passengers. It can operate from a small airport at a downtown location the size of a city block. Instead of the spinning rotors used by the helicopter, the VTOL will use two sets of powerful jet engines. The thrust from one series of lifting engines will allow vertical takeoff, and, as the VTOL gains altitude, turbofan engines will provide a cruising speed between 350 and 500 miles per hour. When it reaches its destination, it will slow down and descend vertically to the next downtown airport. Such a plane will not only shuttle between major airports and mid-city locations but will also carry commuters from suburban areas to their jobs.

Private planes will also undergo radical changes in power and design. Despite a number of improvements, the modern private light plane still operates much like its counterpart of the 1930s. The light plane of the future may be a small compact craft shaped like a thumbnail. Powered with turbine engines, it could use a system of thrust diversion to make short takeoffs or hover at no more than a few inches above the ground. Such a plane could operate from small fields, downtown airports, or even from highways. Depending upon demand, it might be mass produced with the use of advanced plastics and cost no more than a modern high-priced automobile.

Space Exploration

Just as man stands on the threshold of fantastic developments in winged flight, space exploration offers almost infinite possibilities for the future. No longer does he find himself confined to the earth's atmosphere, wondering about the nature of the moon's surface. The early Aerospace Age has already seen him make not one but four trips to the moon and return. And more are planned for the future. Other Apollo flights to the moon depend upon the availability of funds and further developments in the space program. James E. Webb, a former administrator of the National Aeronautics and Space Administration, describes the challenge of space exploration in these words:

> After man reaches the moon—What next? Space presents a limitless future and a limitless challenge; the only ingredients needed to surmount them are man's imagination, his desire, and his inventiveness. A quarter of a century ago, few men would have been bold enough to predict seriously that man would reach the moon by 1970. And now, with the impetus already generated and the growing momentum of the space program, who dares prophesy the monumental strides man will take in the coming decades? The world of space holds vast promises for the service of man, and it is a world we have only begun to explore.

The major challenge of space during the past decade has been to get man and machine into the space environment. The goals of the 1970s are for man to advance beyond the experimental stage of spaceflight and enter a truly operational phase. In the process, emphasis will shift from the astronaut and his control of a spacecraft to the scientist and the laboratory. The most obvious way to achieve this goal will be to establish a permanent space station in earth orbit capable of sustaining people for periods up to six months.

The first step toward a permanent station in space is an experimental space station program known as **Skylab.** Under this program, the National Aeronautics and Space Administration (NASA) plans to launch one or two experimental space stations into earth orbit during the early 1970s. The Skylab or **Orbital Workshop** will be a modified Saturn S-IVB rocket stage completely equipped for manned habitation in orbit (Fig. 80). The rocket's 10,000 cubic foot fuel tank will contain provisions, living quarters, food, and waste facilities to support three men for three different periods up to 56 days each. A two-stage Saturn V launch vehicle will boost the laboratory with an attached Apollo Telescope Mount (ATM) into an orbit about 265 miles above the earth.

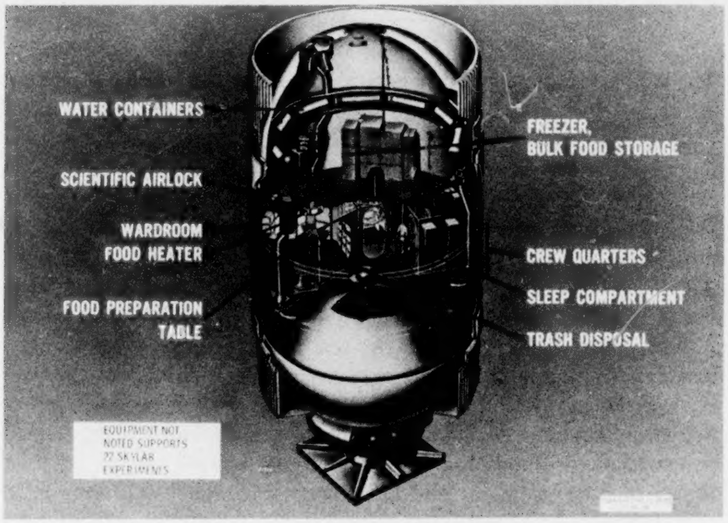
WATER CONTAINERS
SCIENTIFIC AIRLOCK
WARDROOM FOOD HEATER
FOOD PREPARATION TABLE
FREEZER, BULK FOOD STORAGE
CREW QUARTERS
SLEEP COMPARTMENT
TRASH DISPOSAL
EQUIPMENT NOT NOTED SUPPORTS 27 SKYLAB EXPERIMENTS

Figure 80. An artist's concept of the Orbital Workshop which NASA plans to launch into earth orbit during the 1970s. The workshop is a part of the Apollo Applications Program designed to enhance man's knowledge of the universe and his ability to function effectively in the space environment.

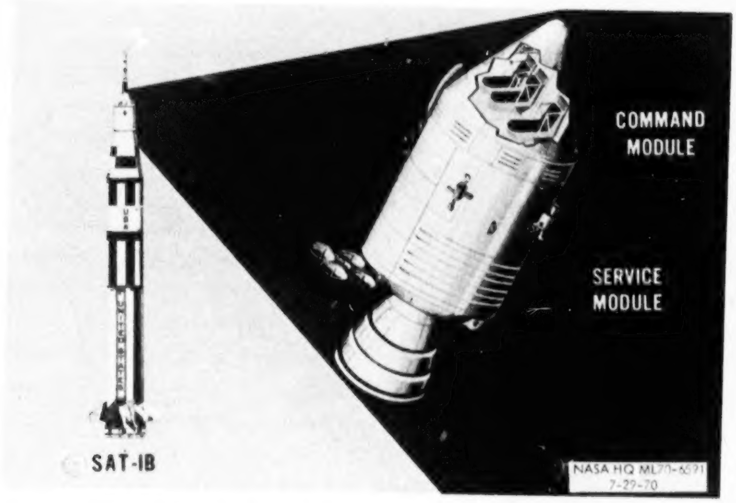

Figure 81. Current plans for the Skylab program envision four missions. The first mission of 28 days will place the laboratory in orbit and conduct initial medical experiments. The second mission of 56 days duration will continue the medical experiments and begin another series of experiments in solar astronomy. The third mission, also of 56 days duration, will focus on earth applications.

The ATM is a solar observatory equipped with instruments to pick up ultraviolet light, X-rays, and visible light radiations from the Sun.

On a smaller Saturn 1B launch vehicle, a command and service module will carry three astronauts into a similar orbit with the Orbital Workshop. The astronauts will rendezvous and dock with the workshop and then prepare it for habitation. Pressurized with its own atmosphere, the workshop will permit the occupants to work and relax without the excess weight of their space suits. After conducting a number of experiments, the astronauts will leave the workshop in orbit and return to the earth in the command and service module. Another crew will replace them and conduct experiments in medicine, communications, meteorology, and astrophysics. From the Skylab program, scientists hope to obtain additional information about man's physiological and psychological responses in the space environment, his capacity for flights of long duration, and his ability to conduct experiments in space (Fig. 81). The ultimate objective is a permanent orbital space station.

Scientists are already at work on designs for a permanent space station that will remain in orbit for a period of 10 or more years. The sta-

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tion will consist of a centralized core module that may be modified with attached or detached modules to meet changing requirements. It will serve as a national research center similar to government and industrial laboratories on the earth. It will provide pilot plants for the introduction of commercial activities in space similar to the communications satellites now in operation. For years, scientists have studied the possibility of an **orbiting space station** for use as a base for launching missions to the moon and into deeper space. A permanent space station will serve not only as a supply and transfer facility but also as an assembly point for space vehicles too large to be launched directly from the earth's surface. For these and similar operations, **space tugs***—specialized shuttle vehicles designed exclusively for use in space operations—would be used. Crews and supplies would be brought to the station by an earth-to-orbit shuttle vehicle and then transferred to another shuttle vehicle propelled by a nuclear engine for flights into lunar or interplanetary orbit.

Weighing up to 100,000 pounds, core stations may have as many as five decks. Two decks will be devoted to living, eating, sleeping, and controlling the space station. One will be used to receive and store supplies. One will contain an environmental control system to maintain a pure, breathable atmosphere and a water management system to reclaim waste water for reuse. The fifth deck will serve as a laboratory for the conduct of various experimental activities. This deck may be supplemented with other modules containing specialized equipment brought by a proposed space shuttle vehicle from the earth.

Plans for an orbiting space station also include provisions for a round-trip or shuttle transportation system between the earth and the station. Such a system will be used to rotate personnel, re-stock perishable supplies, return cargo from orbit to the earth, deliver equipment, repair satellites, or perform space rescue missions. The **space shuttle** will be the first true aerospace vehicle in the sense that it will take off, fly through the atmosphere, go into orbit, return to the earth, and land like a modern airliner.

As currently envisioned by NASA scientists, the space shuttle will be a rocket plane consisting of two stages, an orbiter and booster, united piggy-back style. The booster or lifting body will be larger than a Boeing 747 and the smaller orbiter about the size of a Concorde supersonic transport. It will be a fully reusable vehicle capable of carrying a 50,000-pound payload, including passengers and cargo. The

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* To be used in moving components of orbiting space station's or aerospace vehicles from one point in space to another.

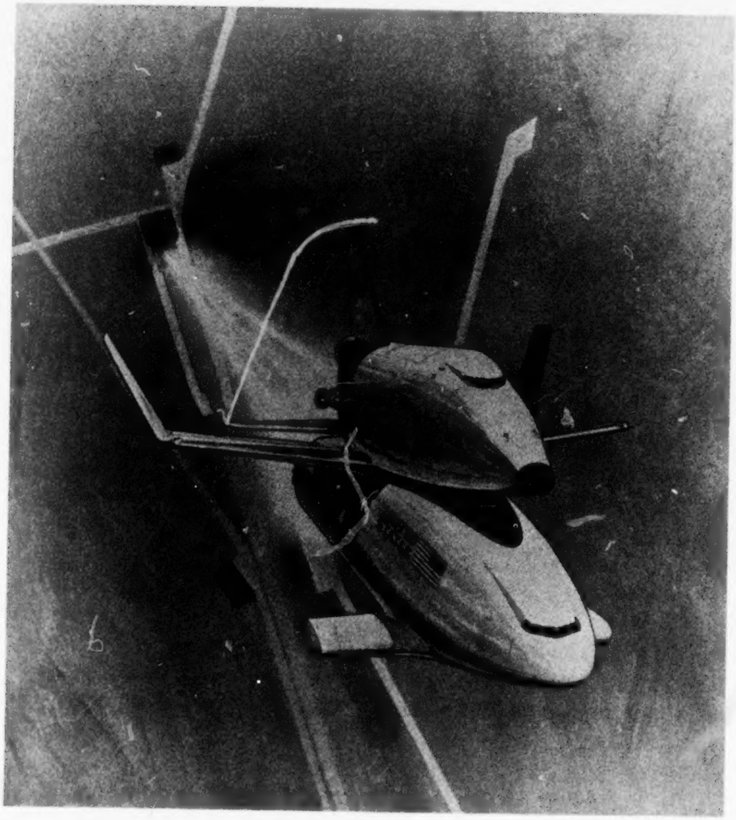

Figure 82. An artist's concept of a proposed reusable space shuttle currently being studied for earth-orbital use during the 1970s. This concept calls for a two-stage vehicle that can be launched vertically. Both stages would return to earth and land like a conventional multiengine aircraft. The shuttle has many potential uses: industrial and scientific experiments, weather and communications satellite operations, and defense missions.

cargo compartment will be at least 15 feet in diameter and 60 feet long (Fig. 83).

After a vertical takeoff, the twin shuttle will soar to a height of about 40 miles above the earth and reach a velocity of about 6,800 miles per hour. At this point, the booster will separate from the orbiter, return to the earth, and make a **conventional landing.*** The orbiter stage will then go into orbit and circle the earth for as long as 30 days.

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* A landing made on a runway.

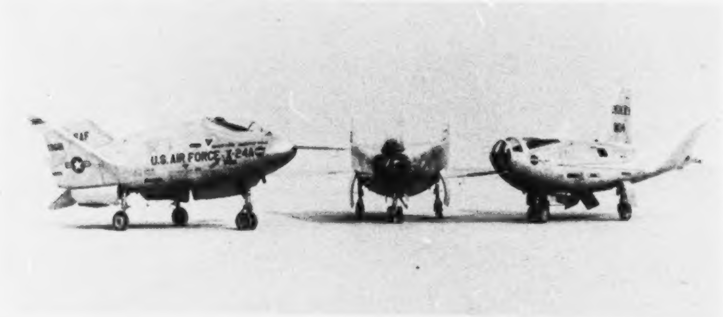

Figure 83. Three manned lifting bodies currently being flight tested by NASA's Flight Research Center are (L-R) the X–24, M–2, and HL–10. The three wingless craft are possible prototypes of future space shuttle craft capable of supplying men and material to orbiting space stations. The X–24 is a USAF design; the M–2 and HL–10 are NASA designs.

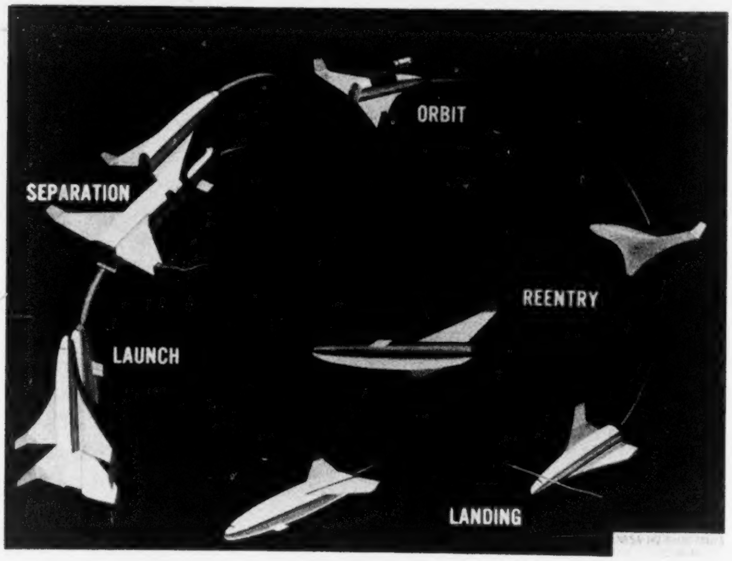

Figure 84. This drawing illustrates the latest approach to a space shuttle mission profile as outlined by Charles W. Mathews during a Space Shuttle Briefing on 1 February 1971 at the Manned Spacecraft Center. As shown here, the two-stage vehicle would take off vertically under rocket power with the orbiter portion in a piggy-back mode atop the booster. After the booster has launched the upper stage toward an earth orbit, the booster would return to the earth and make a horizonal, conventional-type landing on a runway. The upper stage would proceed on a very high-speed and therefore high-heated reentry before landing horizontally on a runway.

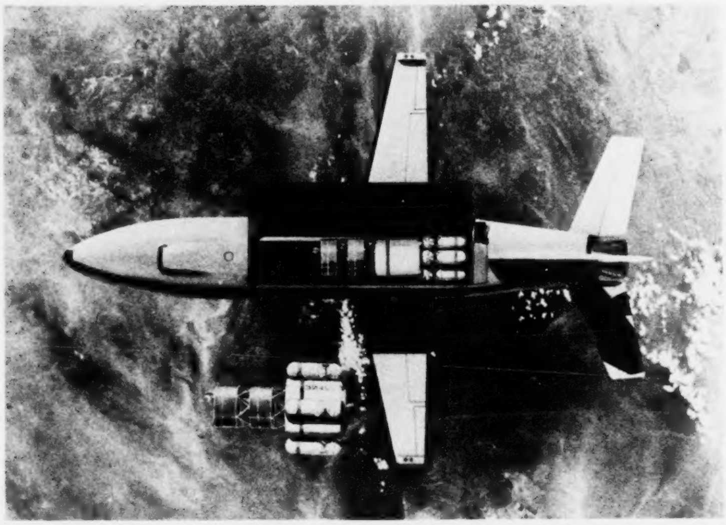

Figure 85. An artist's concept of a reusable space shuttle with a payload in its cargo compartment.

When it completes its mission, it too will reenter the earth's atmosphere and make a conventional landing. Both stages of the shuttle vehicle can be used for as many as 100 additional shuttle excursions over a period of years (Fig. 84).

The shuttle plane will not only serve as a ferry between the earth and an orbiting space station. It will also provide a means of retrieving and repairing unmanned satellites for further use or function as a short-term orbiting laboratory (Fig. 85). It could eventually become the backbone of a space transportation system that includes the shuttle, a space tug, and a nuclear-powered stage for transporting men and cargo between the earth and the moon. If and when the space station and the shuttle system become operational, it will no longer be necessary to limit space flight to persons trained only as test pilots. Scientists, technicians, and others can accompany the flight crew to learn more of the space environment, maintain other space vehicles, and determine ways to apply space research to the solution of earth problems.*

There are at present no plans for manned interplanetary flights. Some scientists believe that unmanned, automated vehicles can perform the same functions on interplanetary missions that man can perform. Others, like Dr. Ernst Stuhlinger, believe that man should build nuclear-powered spaceships and visit the planets in person. Dr. Stuhlinger once commented:

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* AE-I, *Spacecraft and Their Boosters*, contains further details on future developments in aerospace.

> We could make the round trip to Mars in about 14 months, but I would not recommend that man ever attempt to go into deep space in a single vehicle. For the exploration of Mars, we should send a small armada of spaceships. If something happened to one of them, the crew of about eight men could transfer to another one and keep going.

Still others believe that man should continue to search for life on stars beyond the solar system. But even if he should develop a propulsion system that will carry him at the speed of light (186,000 miles per second), he would still need four and one-half years to reach the star nearest the earth, **Alpha Centauri.** At least for the present, orbital or lunar observatories may be his best method for communicating with other star systems.

Regardless of the direction taken by the US space program or the pace at which it advances, the United States will no doubt continue to move forward in space exploration. Astronaut John Glenn puts it this way: "Whenever man has had the means of exploration and discovery, history shows that he has had the courage to make the journey—no matter where it might take him."

WORDS AND PHRASES TO REMEMBER

- aerospace
- all-inertial guidance system
- astrophysics
- boundary layer of air
- conventional landing
- elliptical orbit
- gas turbine engine
- homing device
- orbiting space station
- pods
- prototype
- radio telemetry
- ramjet
- satellite
- sonic barrier
- space shuttle
- space bugs
- supersonic transport
- titanium
- turbofan engine
- turbojet
- turboprop
- variable-sweep wings
- vertical flight aircraft

NAMES TO REMEMBER

- Alpha Centauri
- Hermes program
- Orbital Workshop
- Operation Bumper
- Redstone
- Skylab
- Wernher von Braun

QUESTIONS

1. Why is the term "aviation" an inadequate reference to the flight vehicles that characterize the Aerospace Age?

2. Discuss some of the problems faced by engineers as the speed of the jet airplane increased.

3. What advantage does the turbofan engine have over the turbojet? What problem led to the creation of the ramjet engine? Why did the commercial airlines hesitate to use jet engines? Why is the jet engine especially attractive for military aviation?

4. Name some of the most outstanding early American jet fighters. What was the first American jet fighter to achieve supersonic speeds? Name and describe some modern supersonic fighters and bombers.

5. How does modern commercial air travel differ from airline travel of 40 years ago?

6. Describe the most outstanding airliners in operation during the first decade following World War II.

7. Name and describe the first pure jet airliner to enter commercial service in the United States. What is the difference between the Boeing 747 jetliner and other more conventional commercial jets?

8. Trace the major developments in rocketry since World War II that brought man into the Space Age.

9. Describe the Saturn/Apollo spacecraft.

10. Discuss possible future developments in winged flight, including subsonic airliners, vertical flight aircraft, and private planes.

11. What possible developments can be expected in the exploration of space for the immediate future? (Include orbiting space stations, space shuttle, spacecraft, etc.)

THINGS TO DO

1. If possible, visit a NASA installation or an Air Force missile site. Observe the design of modern missiles and spacecraft.
2. Collect pictures of early American jet fighters and bombers for your scrapbook. Continue with pictures of modern military jet aircraft.
3. Add pictures of the most outstanding four-engine airliners in operation during the decade following World War II.
4. Continue your scrapbook with pictures of modern jetliners.
5. Try to find additional pictures of future aerospace vehicles, such as the supersonic transport, the space shuttle, and an orbiting space station.

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